Section 451
Issue No. 2
September 1979

TELEPHONE NOISE MEASUREMENT AND MITIGATION

CONTENTS

List of Tables

1. GENERAL

1.1 This section provides REA borrowers, consulting engineers, contractors and other interested parties with technical information for use in the design and construction of REA borrowers telephone systems. It is written to provide an understanding of noise in the telecommunications network. Techniques for measurement, analysis, isolation and solution of noise problems will be discussed in subsections. Discussion will be directed primarily to 60 Hertz and its harmonics and their effects on the telephone system.

1.2 This revision replaces REA TE&CM 451, Issue No. 1, dated November 1965 and is reissued to reflect advances in the state of the art of noise measurement and mitigation.

1.3 Power companies today are confronted with an increasing load demand. Telephone companies are utilizing more electronic equipment in their plant operations. Both power and telephone companies are under economic and environmental pressure to use joint right-of-ways. It is essential that inductive coordination problems be resolved from an overall system approach so that advantages of joint random plant and shared rights-of-way may be achieved. If maximum compatibility is to be realized, the telephone engineer will need an understanding of power system problems and the power engineer will need an equal understanding of telephone system problems.

1.4 There is always some noise present on telephone lines. In very small amounts it may be undetected while in slightly greater amounts it becomes annoying to the telephone user. Greater amounts will degrade transmission performance and, in more severe cases, noise can render a connection unusable for conversation. Any disturbance which interferes with the reception of desired sounds by the human ear is noise. Telephone line noise is becoming an increasing problem as demands for power and telephone services grow resulting in additional emphasis by the telephone industry toward its control. There is also usually some longitudinal induced 60 Hertz voltage present on telephone lines. Depending on the magnitude this can produce equipment and personnel safety problems. (See paragraph 3.27).

1.5 Overall noise in a circuit may be a combination of different types of noise, each from a different source. Several of these are outlined in Paragraph 2. This section, as noted in Paragraph 1.1, is primarily concerned with the noise induced by harmonics from 60 Hertz power lines. Induced noise from power lines is the predominant type experienced in telephone lines. No attempt is made herein to discuss in detail the various other types of noise. Some of the more prominent of these can be controlled by proper equipment design and good maintenance procedures. They are, therefore, discussed in the appropriate sections of the engineering manual.

1.6 Impulse noise is receiving more attention in the telephone industry because of its effect on data transmission. Amounts greater than a threshold value produce errors. This type of noise is characterized by a very short time duration and large amplitude. Whereas power line harmonics produce a steady audible sound similar to hum it is, therefore, often referred to as "power line hum", impulse noise does not produce an audible sound. For this reason the effect of impulse noise is not as critical for normal speech transmission as it is for data (transmission of information in pulse form). Impulse noise objectives are given in TE&CM Section 415 but the treatment of circuits for conditioning to data will be included in a separate section of the engineering manual.

1.7 High voltage dc transmission (HVDC) lines are operating or planned in various parts of the country. These have the capability of handling to 2000 megawatts of electric power (at $\pm$ 400 kV during bipolar operation). Due to their close relationship with the 60 Hertz power system, the noise contribution associated with these systems will be discussed in TE&CM Section 451.6.

1.8 The analysis of noise problems cannot be approached in a haphazard manner. The many factors which can contribute to noise in telephone systems can cause considerable confusion in the analysis of noise problems if they are not properly isolated and remedial action taken in the proper sequence.

1.81 It is essential that a systema
specific tests made in the pro
tigation. It is wise to never take any
proven by measurement when working with
procedure, time can be wasted and often

1.82 Noise problems in telephone sy
cases the solutions to these p
the capability of craftspeople. A flow
procedures is included in Appendix A.

2. TYPES OF NOISE

2.1 Although this section is devot
line harmonics, other types ca
the order of magnitude for overall nois
some extent on these. The noise of gre
the others. Voice frequency noise may
origin.

2.2 Acoustic Types of Noise

2.21 Room noise entering the telephone transmitter and reaching the receiver through the sidetone path.

2.22 Room noise entering the telephone transmitter and transmitted in the same manner as speech.

2.3 Electrical Types of Noise

2.31 Electrical Storms

2.32 Inadequate battery filtering.

2.33 Contact noise in switching apparatus.

2.34 Noise from electronic equipment.

2.35 Unintelligible crosstalk from other telephone circuits

2.36 Noise induced from power lines.

3. SIGNIFICANT FREQUENCY COMPONENTS

3.1 Most ac power lines in the United States have a fundamental frequency of 60 Hertz, and the bulk of energy is transmitted at this desired frequency. For reasons discussed later, the alternating voltage or current is never a pure 60 Hertz sine wave, but contains harmonics which extend into the voice frequency range. The magnitude of these harmonic components is small compared to that of the fundamental frequency. Because the telephone set and the characteristics of the human ear are far more sensitive in the range of the harmonic frequencies and furthermore because inductive coupling efficiency increases with frequency, the harmonics are of greater importance to the telephone system than the fundamental frequency component.

3.2 There is also induction at the fundamental frequency called "low frequency induction." Low frequency induction is normally a protection and safety consideration, rather than a noise problem, because of the transmission characteristics of the telephone set and the human ear both of which attenuate these lower frequencies.

3.21 An induced fundamental frequency voltage of fifty volts is the maximum permissible on a cable pair (See paragraph 12.6(a)). This level is related to personnel safety. Signaling problems can occur with fundamental frequency voltages of lower magnitude. Some electronic equipment can become noise sources with relatively low levels of 60 Hertz voltage (10 to 15 volts).

3.22 Longitudinal voltages in excess of 50 volts are becoming more commonplace as the demands for power increase. Where excessive fundamental frequency voltage exists it should be reduced before proceeding further with any noise investigation. (See paragraph 15).

3.3 Induction at frequencies which are harmonics of 60 Hertz is termed "harmonic induction" or "noise frequency induction" and this section is primarily devoted to this type of noise induction. The range of harmonic frequencies which may become involved in noise problems can be from 180 to approximately 4000 Hertz. This represents a range from the third to the 67th harmonic of the 60 Hertz fundamental frequency.

3.4 The human ear is sensitive only to frequencies in a range of approximately 20 to 20,000 Hertz, but is not equally sensitive to sounds of equal intensities at all frequencies in this range. It is most sensitive, on the average, to frequencies of about 2000 Hertz. The variation in sensitivity is somewhat in accordance with the following, shown in Table I, (for average young people).

TABLE I

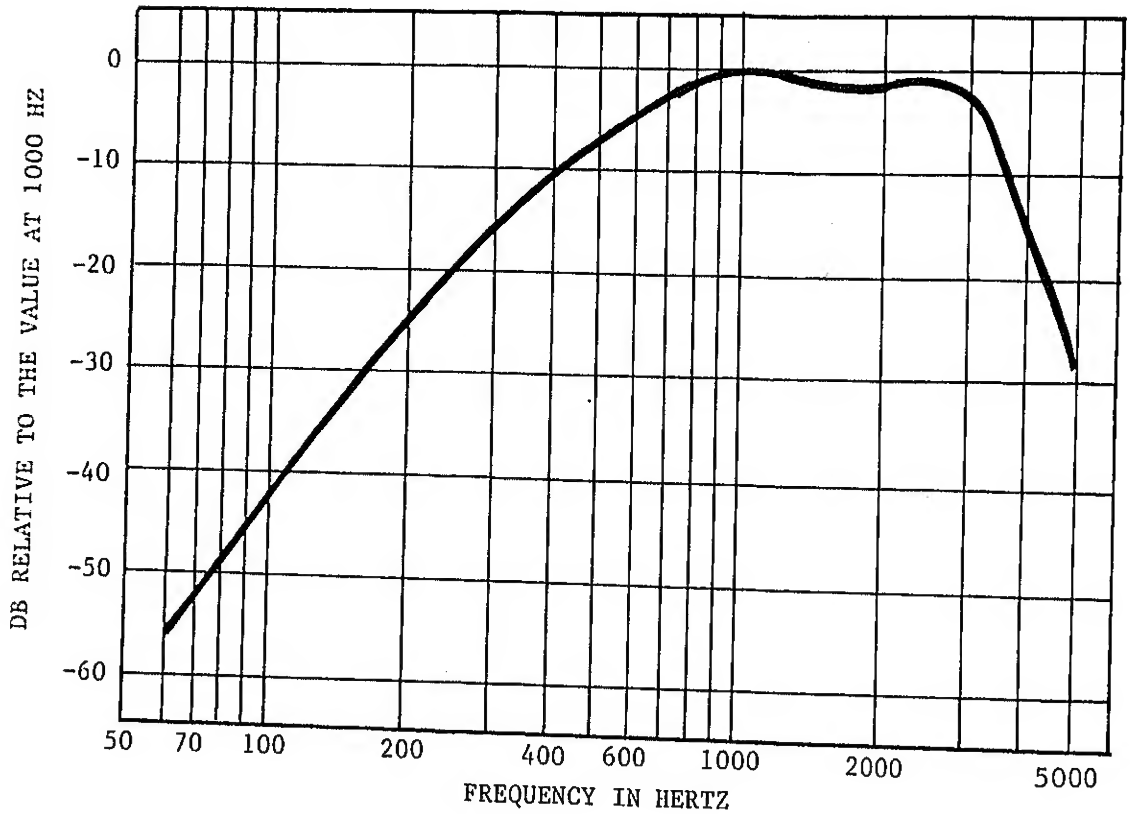
Frequency in Hertz	Minimum Acoustic Pressure in dBRAP for Perception
20	80
60	43
100	32
200	18
300	14
400	11
500	7
1000	3
2000	-3
5000	-5

3.41 The above table indicates that a sound at 60 Hertz would have to be about 40 dB higher than one at 1000 Hertz for minimum perception in both cases. Obviously, one of the measures of the disturbing effect of noise is its frequency composition, in addition to its intensity. Reference Acoustic Pressure (RAP) is a measure of sound level. Zero dBRAP is 0.0002 dynes per square centimeter in a plane wave limitation as to how loud a sound can be before it be subject and is not perceived as sound in the ordinary

3.42 Like the human ear, the telephone set has a tic (weighting) which is a function of frequ connecting to the telephone set tends to modify this 1 shows the weighting effect as it applies to the 50(

This curve is the present standard[1] for measuring nc "C-Message Weighting" to distinguish it from other we used in the past.

[1] Evaluation of Message Circuit Noise, Bell Syst July 1960, pp. 879-909.



RESPONSE IN DECIBELS INDICATING RELATIVE INTERFERING EFFECT, C-MESSAGE WEIGHTING

FIGURE 1

3.421 An examination of this curve reveals the following:

At the frequencies of 180, 360 and 540 Hertz, for example, the reaction by a subscriber using a 500 type telephone set will be such that he hears these frequencies less loud by 27.5, 16.5 and 6 dB, respectively than had the frequency been 1000 Hertz and of the same magnitude. Stated in a different way, if the individual frequencies of 180, 360 and 540 Hertz are to produce the same stimulus (psychological reaction to the listener) as a 1000 Hertz tone, they must be increased in level by 27.5, 16.5 and 6 dB compared to the level of the 1000 Hertz reference tone. This illustrates that different frequencies have different effects on hearing when using a 500 type telephone set. When applied to noise, this means that some harmonic frequencies have more interfering effect than others. Therefore, even a very small amount of a particular harmonic could be sufficient to cause noisy conditions. The interfering effect of the different frequencies for equal loudness is the basis of any weighting curve (bandpass filter) which is used to measure overall circuit noise. As indicated above, the present standard is C-message weighting and is

used for all noise work in both exchange and toll plant. Basis of reference and use of the C-message weighting is further discussed in paragraph 9.2.

4. THEORY OF COUPLING

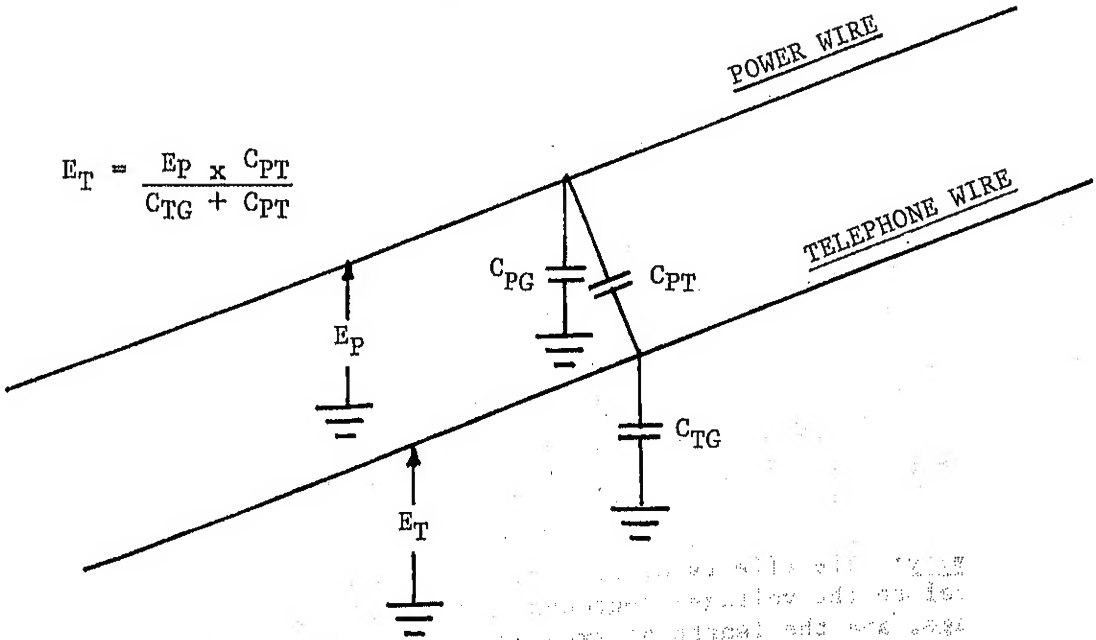
4.1 Historically the process of noise induction has been considered in two categories, electric and magnetic fields from the voltages and currents of the power line, respectively. Their effects need to be considered separately, particularly in the analysis of specific problems, because the actions of voltages and currents from an induction standpoint can be different. Power circuit voltages and currents are also affected differently by changes in conditions. The division of the two categories also coincides with different techniques for mitigating effects of the two sources.

4.2 Before discussing some of the more detailed aspects of noise induction, a brief examination of the general nature of electrical and magnetic induction will be covered. An understanding of how these couplings introduce noise on telephone circuits will be valuable in the analysis of specific noise problems.

4.3 Electric Induction

4.31 Electric induction, normally associated with the voltage on a power line may be visualized by means of the capacitance between a single power wire and a single telephone wire. This relationship is illustrated in Figure 2. Induced voltage between the power wire and ground (E_P) divides over the capacitances between the power and telephone wire (C_{PT}) and the telephone wire and ground (C_{TG}) in proportion to their impedances (in inverse ratio to their capacitances). Voltage on the telephone wire (E_T) is expressed by the relation:

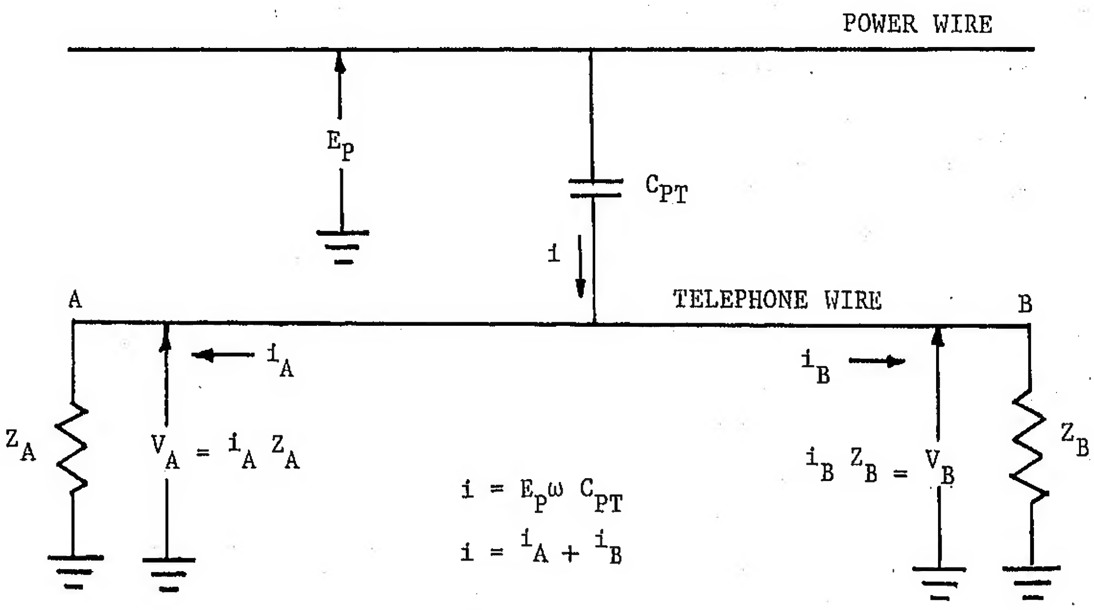
$$E_T = \frac{E_P \times C_{PT}}{C_{TG} + C_{PT}}$$



ELECTRIC INDUCTION

FIGURE 2

4.32 A different method of visualizing the effects of electric induction is shown in Figure 3 for the practical case where the telephone wire is terminated longitudinally in office equipment or is long enough to be effectively terminated in the characteristic impedance of the circuit.



ELECTRIC INDUCTION

Telephone Wire
Terminated In Its
Characteristic Impedance

FIGURE 3

Impedance of the capacitance (C_{PT}) is much greater than the impedances terminating the telephone wire, and hence the current, "i", is practically independent of Z_A and Z_B. However, the division of the total induced current between the ends of the line depends on the relation between the impedances at A and B.

4.33 Voltage-to-ground due to electric induction is the product of the current i_A and the impedance to ground Z_A or the current i_B times Z_B. Since the value of C_{PT} is directly proportional to frequency, the value of i will be directly proportional to the frequency of the power voltage.

4.34 Summary: The effects of electric induction are directly proportional to the voltage-to-ground on the power wire, the frequency of this voltage, and the length of exposure between the power and telephone wires. It is also proportional to the proximity of the lines (C_{PT} per unit length). Where the telephone plant utilizes shielded cables that

are adequately grounded, the shield has the effect of discharging the capacitance. Pairs contained within the shield are virtually immune to capacitance coupling (electric induction). This form of coupling is still of importance where there is open wire plant.

4.4 Magnetic Induction

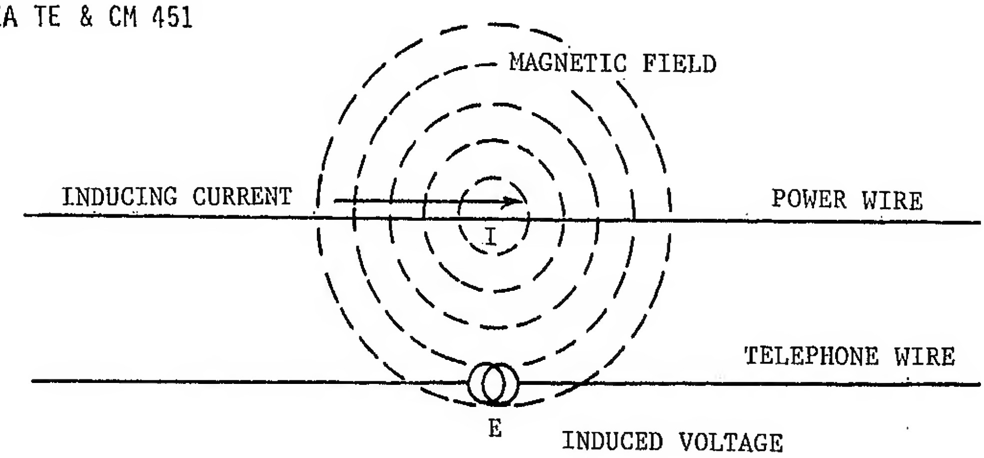
4.41 Magnetic induction, on the other hand, is a function of the current flowing in the power system and is therefore of primary concern. Figure 4 shows that the current in the power wire sets up a magnetic field which alternates at the frequency of the inducing current. A voltage is induced along the telephone wire which is proportional to the rate of change of the magnetic flux just as a secondary winding in a transformer has a voltage induced along it. Figure 5 illustrates how the entire magnetically induced voltage appears between the open end of the telephone line and ground. Figure 6 shows how the voltage-to-ground at each end of a terminated telephone line depends on the terminating impedances and the total magnetically induced voltage (E).

4.42 Where the telephone plant utilizes shielded cables both the shield and the pairs inside are exposed to the flux generated by the power line. Hence, both will have induced voltage. This occurs whether the telephone plant be located above or below the ground. Completion of the shield circuit by grounding at both ends allows a current to flow. This current flow will induce a counteracting voltage on the telephone pairs within the cable shield which tends to cancel some of the original induced voltage. Fundamental frequency cancellation is small. As frequency increases so does the cancellation. This will be discussed in detail in Paragraph 5, "Shielding".

4.43 Summary: Magnitude of the induced voltage is directly proportional to the power line current, to the coupling between the power and telephone lines (which is proportional to the exposure length) and to the frequency of the power line.

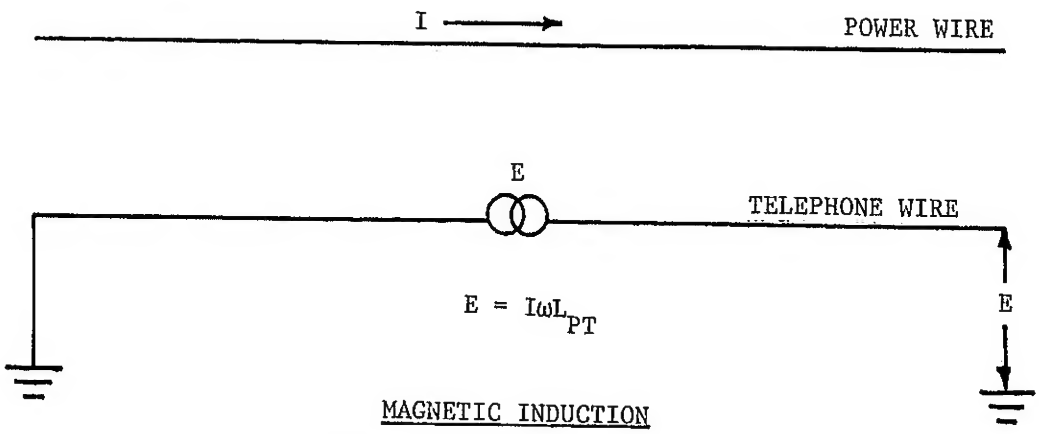
4.5 Conductive Coupling

4.51 There is a form of coupling which is dependent on current flow through the earth. The majority of power systems in the United States use a multigrounded neutral (MGN) conductor. This provides an alternate path to that provided by the earth for the flow of current back to the source. In these systems current will flow through both the neutral conductor and the earth path. The division of current is determined by the characteristics of the particular power system and associated grounds. As much as 60 percent of the current may normally return through the earth with only 40 percent via the neutral conductor. There are still a few power systems operating with a unigrounded "Y" configuration (See paragraph 7.32). In such systems there is no current flow through the ground path.



MAGNETIC INDUCTION

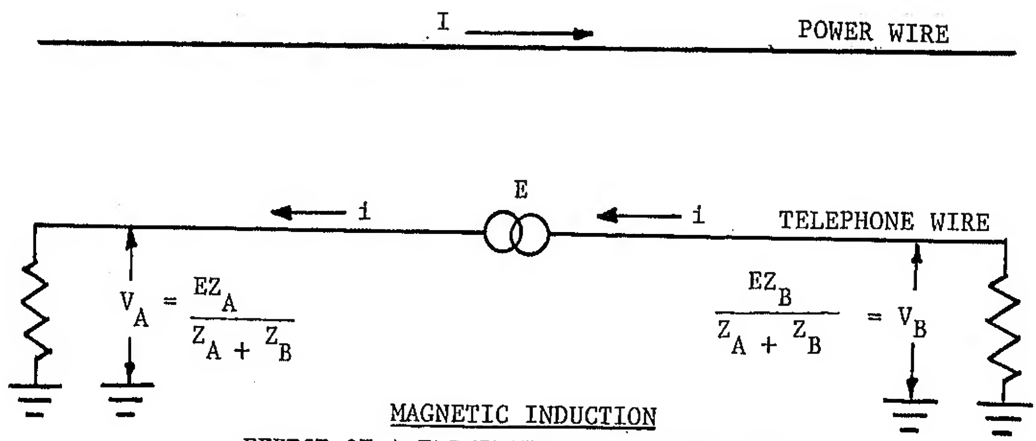
FIGURE 4



MAGNETIC INDUCTION

TELEPHONE WIRE TERMINATED IN ITS
CHARACTERISTIC IMPEDANCE

FIGURE 5



MAGNETIC INDUCTION

EFFECT OF A TERMINATED TELEPHONE LINE
ON VOLTAGE-TO-GROUND

FIGURE 6

4.52 When earth resistivity is high in the vicinity of power system grounds this earth return current may now divide between the earth path and a telephone cable shield which is grounded near it. This mode of coupling is sometimes referred to a conductive coupling. The current flowing in the shield will induce a voltage on the cable pairs which can result in increased circuit noise. This will be discussed in more detail in paragraph 5, "Shielding".

4.53 Summary: Cable shields carry a portion of the earth or ground return current from the power system. This current flow in the shield will induce a voltage in the cable pairs which can result in noise in the telephone circuits.

5. SHIELDING

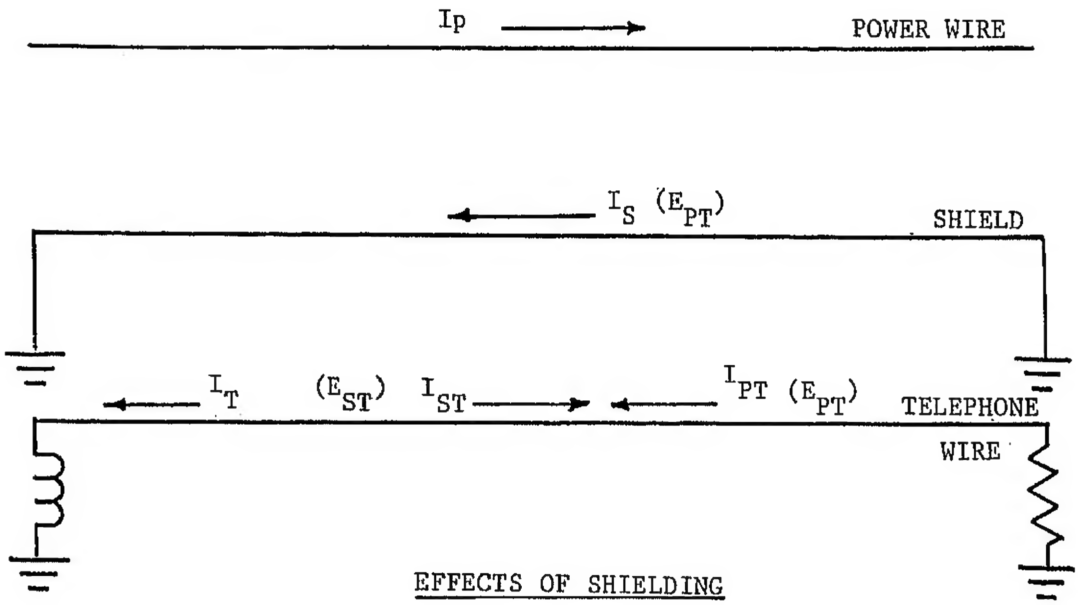
5.1 Examination of the effects of shielding and its relationship to longitudinal induced voltages on a telephone line is important. Shielding can effectively reduce the voltage, especially harmonic voltage, induced in cable pairs when the shield is continuous and effectively grounded along the exposure. In many instances noise problems are a result of inadequate shielding of telephone cables due to lack of continuity rather than power company sources.

5.2 The importance of shield continuity can best be explained by a review of how shielding works. While the entire subject of induction and the shielding function is complex and beyond the scope of this practice a simplified explanation will be sufficient to illustrate its importance. A more detailed discussion of shielding will be presented in TE&CM Section 452. Figure 7 shows that when a current (Ip) flows in a power conductor with earth return, a magnetic field is generated around the conductor. If a telephone cable is located in this field a voltage (Ept) will be induced in the shield and conductors of the telephone cable. The magnitude of voltage (Ept) may be determined for the condition where no shielding exists by calculating the mutual impedance between the power conductor and the telephone cable. Mutual impedance is defined as the voltage per unit length induced in the disturbed conductor (telephone cable shield or conductor) per ampere of current in the disturbing circuit and associated earth return path. Mutual impedance, which will be discussed in detail in TE&CM Section 452, is a complex value based on earth resistivity, frequency and separation between the disturbing and disturbed conductors.

5.21 When the telephone conductor is grounded through a load a current (1_{PT}) will flow through the conductor. This current at any instant is 180° reversed (out of phase) with respect to the power conductor current as shown by the arrow in Figure 7.

5.22 For practical purposes, the cable shield is spaced almost the same distance from the power conductor as the cable conductors. Consequently, it may be assumed the same voltage will be induced on the shield as on the cable conductors. When the shield is grounded at both ends a current (1_S) will flow in the shield circuit in the same direction as the current (1_{PT}) in the cable conductors. This current flow with its

associated earth return path will generate a magnetic field and a counteracting voltage (E_{ST}) will be induced on the telephone cable conductors via the mutual impedance between the shield and conductors. This mutual impedance can be defined in simple terms as the voltage per unit length induced in the disturbed telephone cable conductor per ampere of current in the disturbing shield circuit and its associated earth return path. A current (1_{ST}) will flow in the telephone cable conductors due to the induced voltage (E_{ST}) in the opposite direction to that induced from the power system (1_{PT}) as shown by the arrow in Figure 7.



EFFECTS OF SHIELDING

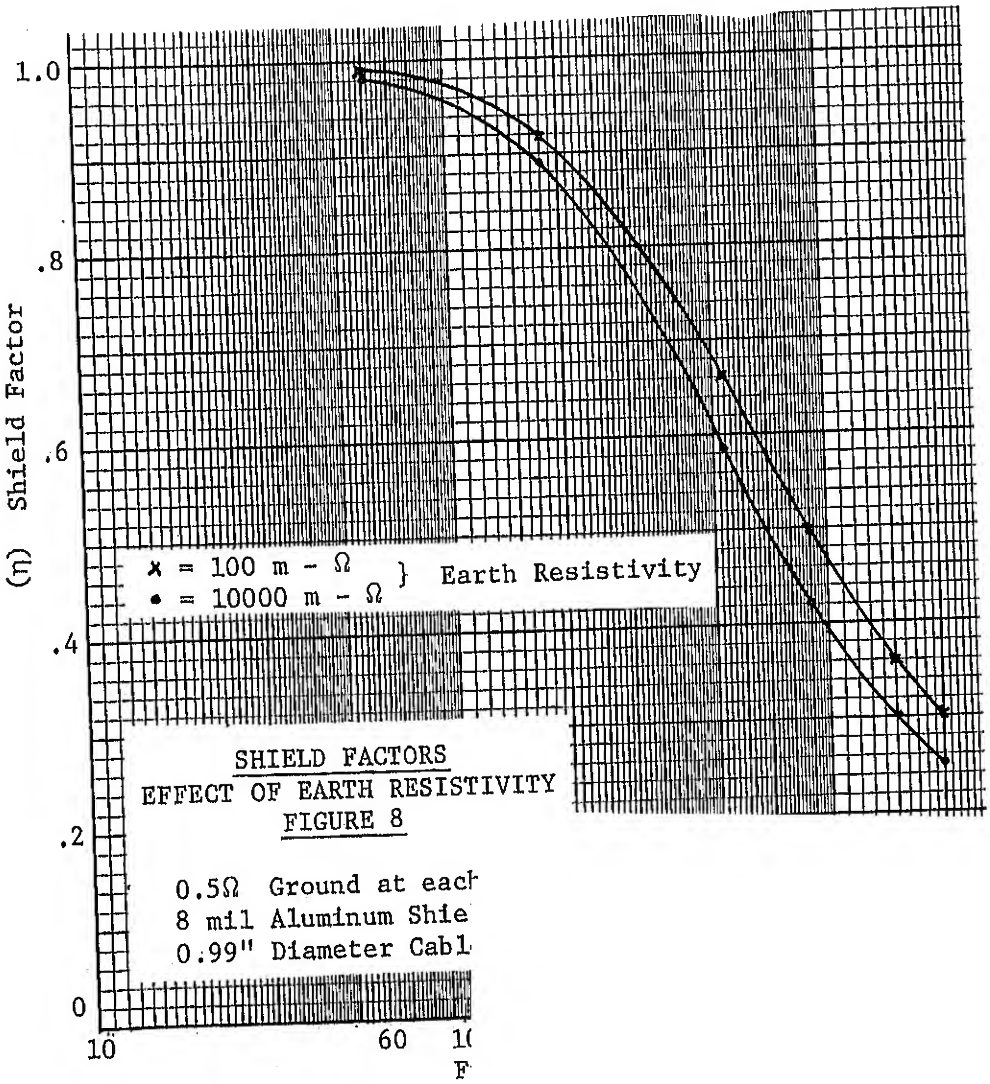
FIGURE 7

5.23 If a voltage equal in magnitude to that induced in the cable conductor from the power conductor could be induced in the cable conductor from the shield total cancellation would result and there would be no noise. The probability of such an ideal state existing in practice is practically nil. The amount of shielding may be expressed as the percentage voltage reduction in the disturbed circuit (telephone cable conductor) resulting from the introduction of a shielding system when the current in the disturbing circuit remains fixed. It is usually more convenient to employ a shield factor (η) in actual calculations. This may be defined as the ratio of the resultant voltage in the disturbed circuit, after introduction of a shielding system, to the nonshielded induced voltage, each resulting from the same current in the disturbing circuit. The effective coupling between the disturbing and disturbed circuits in the presence of a shielding circuit is equal to the mutual impedance between the circuits in the absence of the shielding circuit multiplied by the shield factor. A low shield factor represents a desirable condition, since it indicates a large reduction of voltage.

5.231 A shielding circuit is most effective when the total resistance including both the shield conductor resistance and the resistance to earth of the ground connections is small, if either part of the total shield circuit is fixed, there is a practical limit beyond which it is uneconomical, based on the results obtained, to further lower the variable resistance.

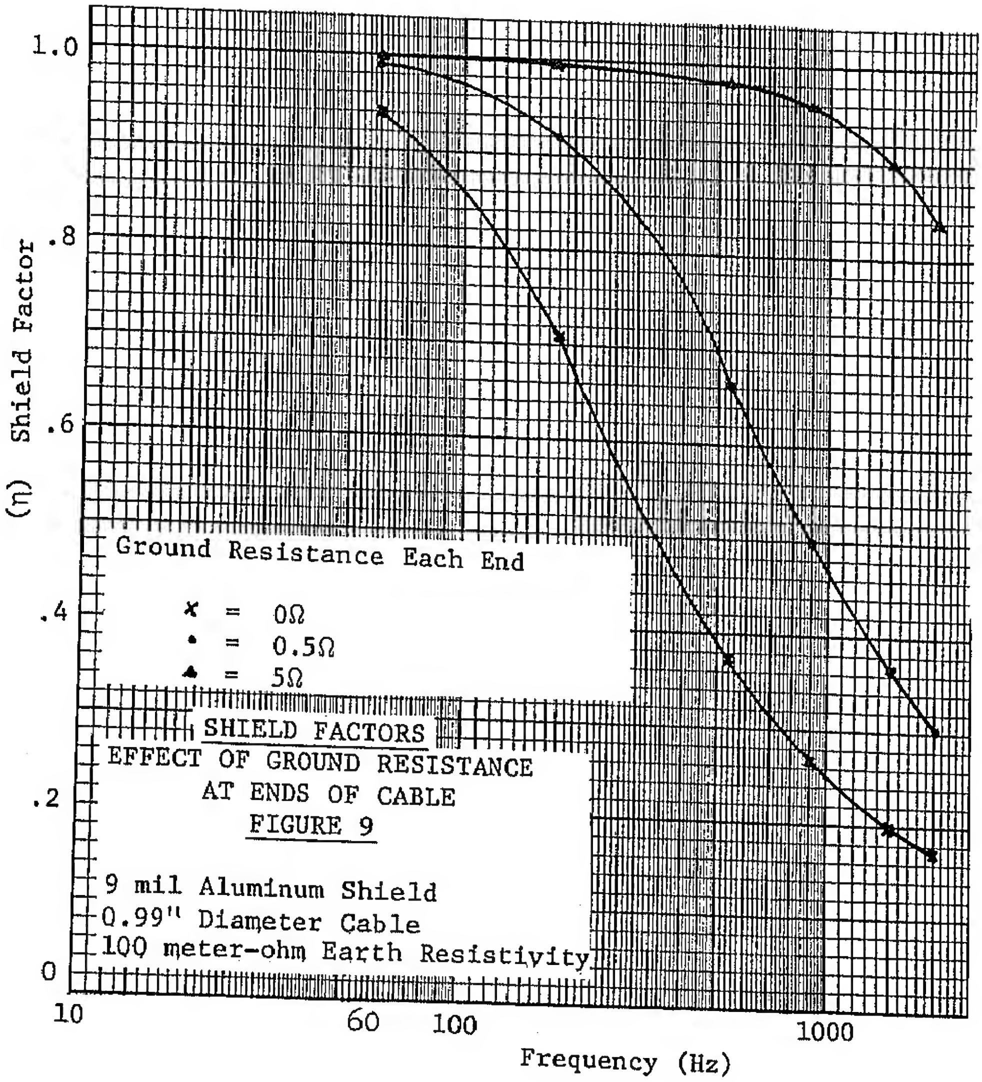
5.232 Earth resistivity, resistance to earth of ground connections, resistance of shield conductor, frequency and total length of shielding circuit all have a bearing on the shield factor. Figures 8 through 14, inclusive have been included to illustrate these relationships. Derivation of these figures will be discussed in detail in TE&CM Section 452.

5.233 Variation of shield factor (η) with variations in earth resistivity is shown in Figure 8. Note that there is almost no shielding at the fundamental frequency.



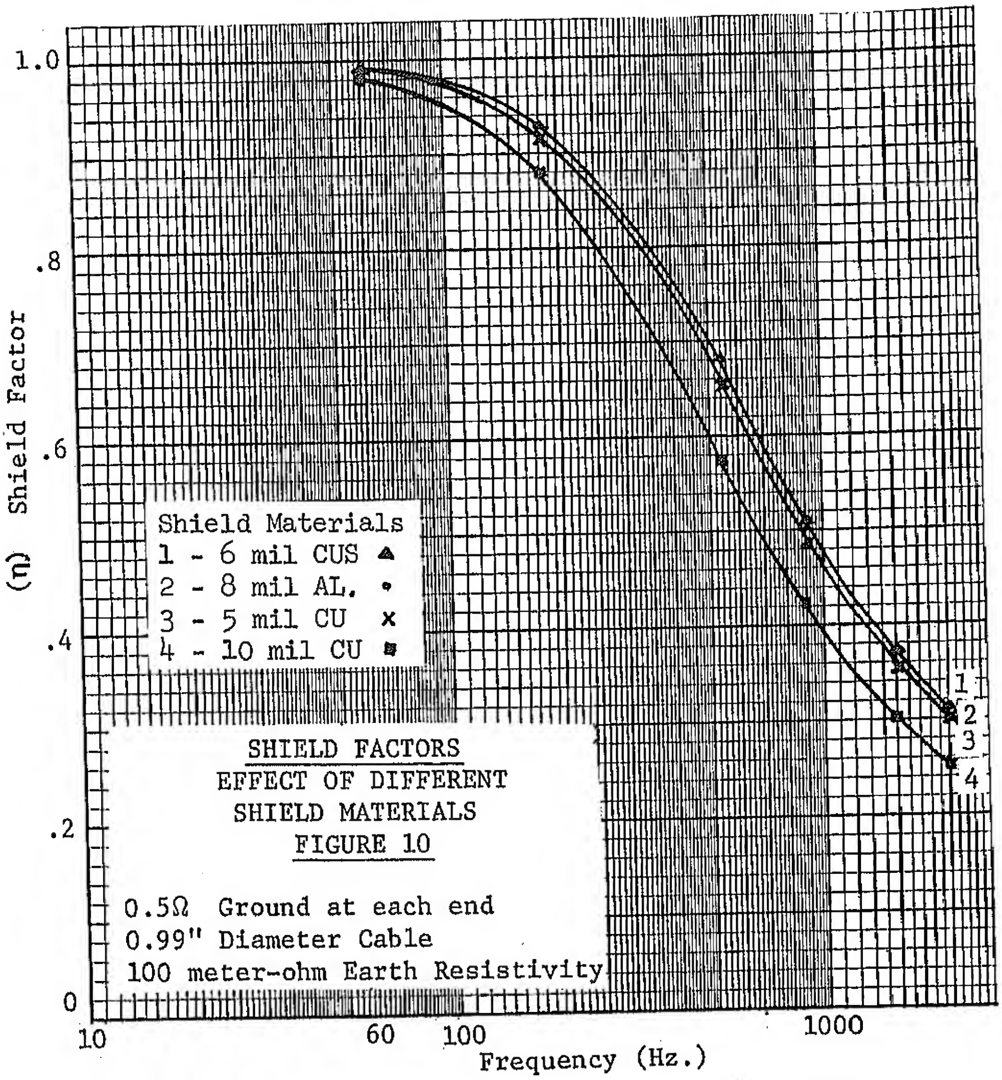
SHIELD FACTORS
EFFECT OF EARTH RESISTIVITY
FIGURE 8

5.234 Figure 9 illustrates the variations in shield factor associated with varying values of resistance to earth for grounded end connections with a circuit one kilofoot in length. It will be shown later that where only grounded end connections exist their effect on the shield factor reduces as the circuit becomes longer.



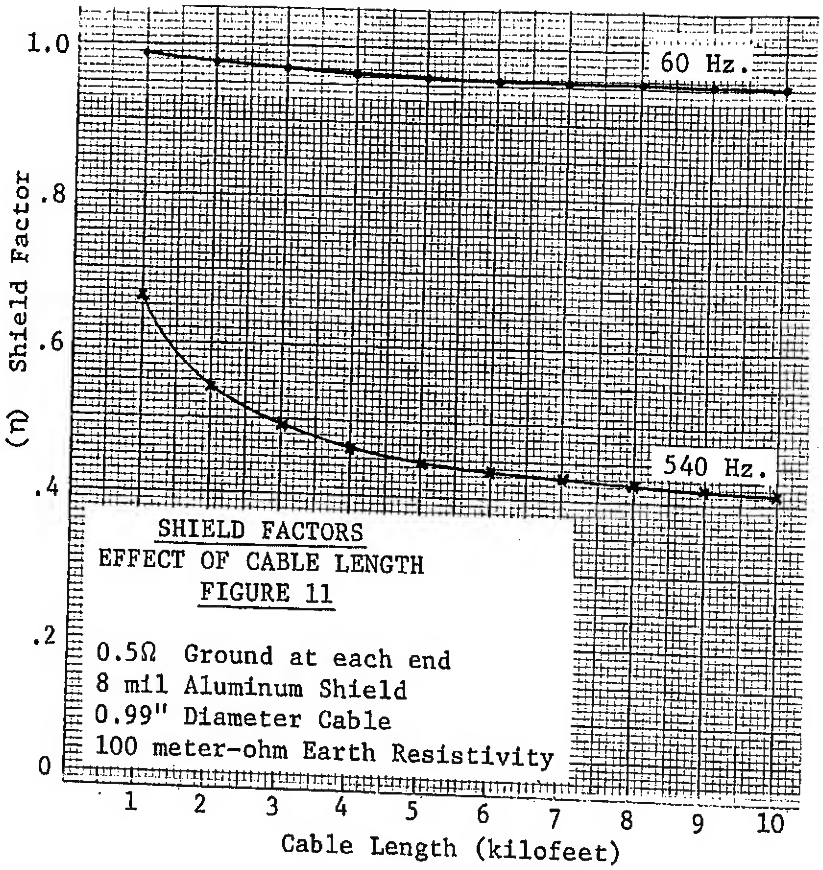
SHIELD FACTORS
EFFECT OF GROUND RESISTANCE
AT ENDS OF CABLE
FIGURE 9

5.235 Variation of shield factor with the various materials commonly used for telephone cable shields is illustrated in Figure 10. Very little improvement can be achieved at the fundamental frequency by substituting 10 mil copper for 6 mil copper steel. At 540 Hertz an improvement of about 16 percent can be attained.



SHIELD FACTORS
EFFECT OF DIFFERENT
SHIELD MATERIALS
FIGURE 10

5.236 Figure 11 shows the shield factors for 60 and 540 Hertz with various lengths of cable with an 8 mil aluminum shield and a half ohm ground connection at each end. At 540 Hertz the longitudinal voltage will be reduced to 42 percent of the unshielded magnitude while at 60 Hertz the shielded longitudinal voltage will be 95 percent of the unshielded level. This demonstrates graphically the low shielding efficiency at the fundamental frequency.

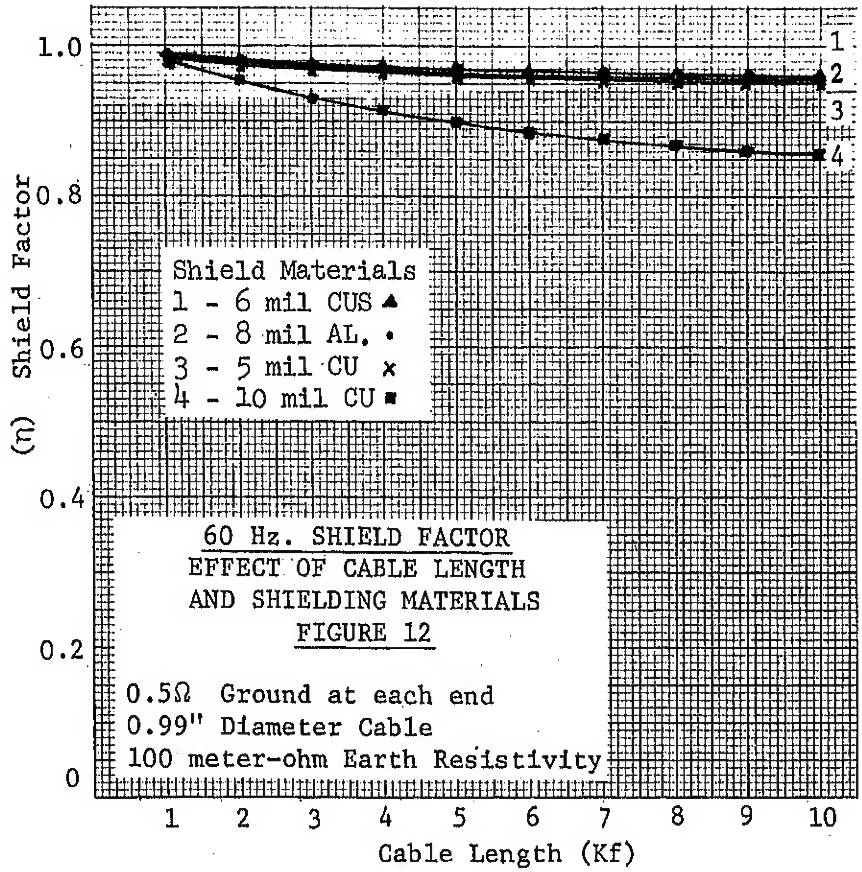


SHIELD FACTORS
EFFECT OF CABLE LENGTH
FIGURE 11

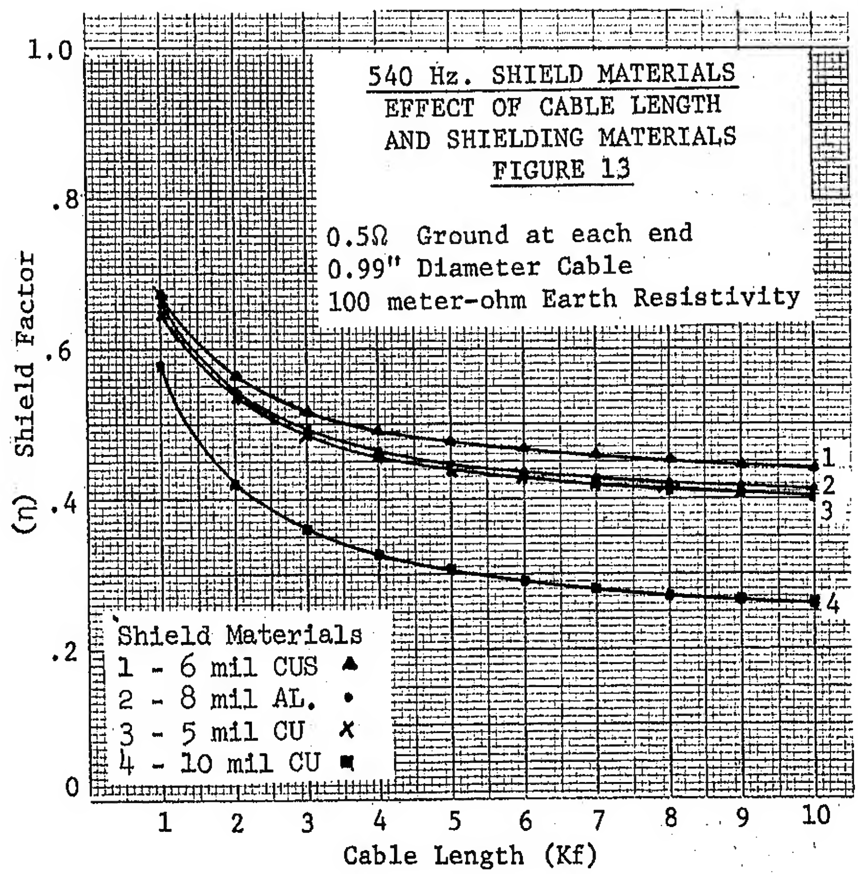
5.237 Effects of various shielding materials at 60 and 540 Hertz, respectively, are shown in Figure 12 and 13, for cables of various lengths. Again, the lack of effective shielding at the fundamental frequency is obvious.

5.238 The differences in shield factor with a ground connection at each end and with intermediate ground connections is illustrated in Figure 14. The condition of only a single ground connection at each end of a cable rarely occurs in actual service. Maximum shielding occurs when there are equal spaced low resistance grounds along the cable shield. This will be discussed in TE&CM Section 451.7.

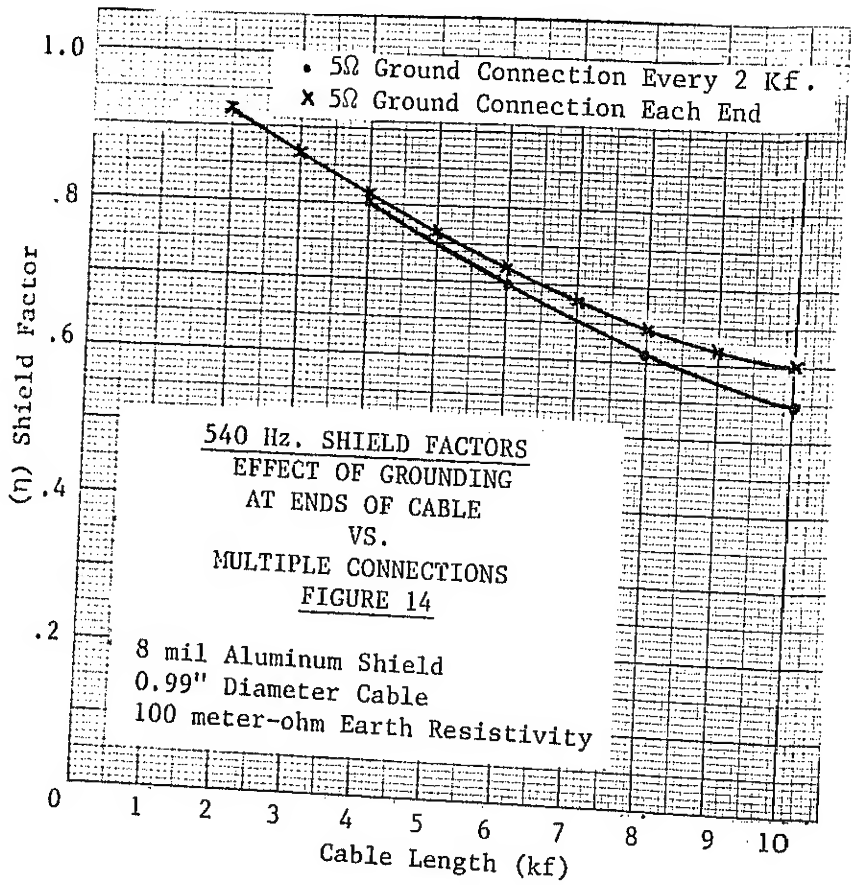
5.3 It is important that the ground connection and shield resistances be kept as low as practical since the magnitude of the counter-acting voltage induced in the cable conductor is the produc of the shield current and the mutual impedance between the cable shield and the cable conductors. If the shield continuity to ground is broken little shield current can flow and there will be no effective shielding. If the ground connection resistance is high, if the shield splice bonds are defective, or if there are high resistance discontinuities in the shield itself, the shielding currents will be reduced and shielding will be less effective. Problems of excessive induced 60 Hertz voltages cannot be corrected by improving the shielding.



60 Hz. SHIELD FACTOR
EFFECT OF CABLE LENGTH
AND SHIELDING MATERIALS
FIGURE 12



540 Hz. SHIELD MATERIALS
EFFECT OF CABLE LENGTH
AND SHIELDING MATERIALS
FIGURE 13



6. BASIC NOISE FACTORS

6.1 Three factors combine to produce the overall noise on telephone circuits from power induction. They are:

a. Inductive influence of the power system (also called power influence). This is a measure of the interfering effect of the harmonics in the system.

b. Inductive susceptiveness or balance of the telephone system.

c. Inductive coupling between the power and telephone system.

6.2 Characteristics of a power circuit with its associated apparatus (company and subscriber owned) determine the character and intensity of the electric or magnetic field which it sets up in the surrounding medium. These characteristics are termed "Influence Factors". Likewise, characteristics of the telephone line with its associated apparatus determine its responsiveness to external electric or magnetic fields. These characteristics are termed "Susceptiveness Factors". There is also the group of factors which relate to the interrelation of neighboring power and communication lines via electric or magnetic induction or both. These are termed "Coupling Factors".

6.3 Inductive interference is the telephone circuit noise resulting from a combination of influence, susceptiveness and coupling. Inductive coordination is the cooperative engineering approach by both power and telephone representatives for providing satisfactory service to their mtual customers. It consists of the control of the three factors (influence, susceptiveness and coupling) to the degree necessary for satisfactory service performance of both systems. Inductive influence of a power circuit in an exposure is determined by the magnitudes of the harmonic currents and voltages present on the circuit.

6.4 All three basic factors must be present in order for a power induction noise condition to exist. The absence of any one of them would eliminate power induction noise completely. In reality complete elimination is impractical and the ultimate power induction noise will be a function of the basic factor that has the highest influence factor.

7. POWER INFLUENCE

7.1 Power systems in the United States usually operate at a fundamental frequency of 60 Hertz. They also act as generators of harmonic frequencies of the fundamental. At the generator terminals the wave form is a relatively pure sine wave.
ties provide a relatively harmonic free f
were possible to maintain a nearly pure
throughout a power system, power line i
fundamental frequency with minimum tele
wave shape distortion can be expected o
sources:

1. Nonlinear properties of t
2. Characteristics of the lc

This wave shape distortion produces the
harmonics present in the current wave f

7.2 Power systems from generation
network of many types of appar
five basic parts: generation, transmis
and customer load.

7.3 The principal types of power systems are three-phase and single phase. Depending on the transformer connection and grounding there are three types of three-phase operation, delta, unigrounded Y, and multigrounded Y. Single phase systems operate with a multigrounded neutral. Configuration of the various systems are shown schematically in Figure 15. Each of these systems has a different potential for power induced interference in the telephone systems.

7.31 <u>Three Phase Delta System</u>: Delta transformer connections are used in some transmission and subtransmission systems. This connection is rarely used in distribution systems. Since there is no neutral wire or ground connection with a delta system the interference potentials are those normally associated with balanced circuits. They are, therefore, dependent upon the balance of current among the three phases and the separation between the power conductors and telephone line.

7.311 There are conditions where delta systems can be a source of interference. When long runs of cable parallel high voltage transmission lines the odd triple harmonics (180, 540, etc.) can reach levels in the telephone plant that exceed acceptable limits.

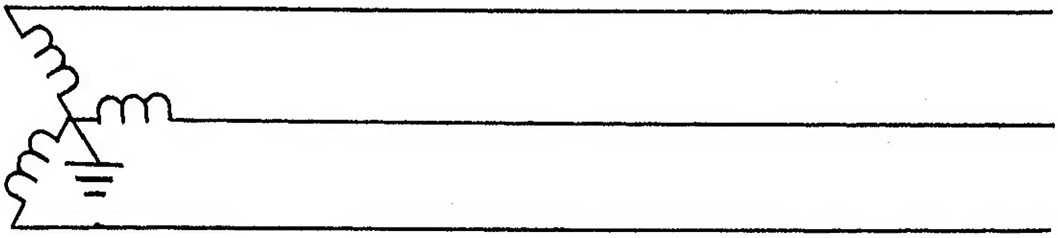
7.312 Under the same parallel conditions described in paragraph 7.311 the induced fundamental frequency longitudinal voltage on the telephone plant can exceed safety limits with only a slight unbalance in the power system. Because of this potential problem long cable runs parallel to high voltage transmission lines should be avoided if at all possible.

7.313 Another potential problem is the effects on nearby telephone plant when a fault condition occurs along a high voltage transmission line. Very little has been written in REA on this important subject and a discussion of protecting against damage from such fault conditions is beyond the scope of this section.

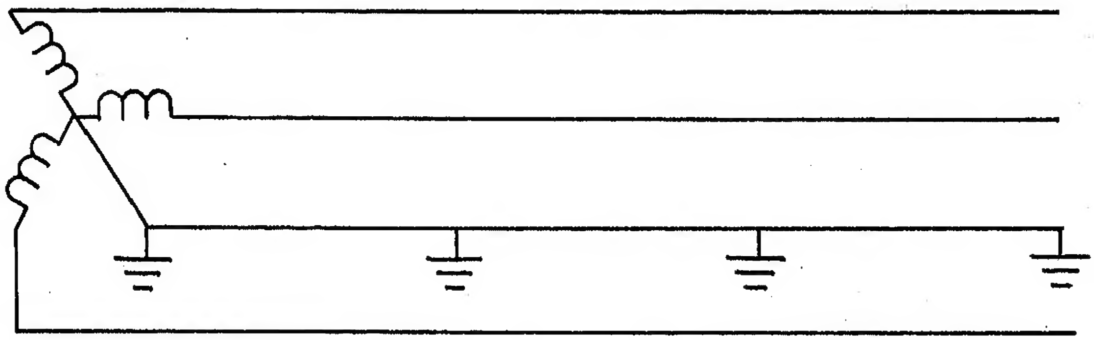
7.32 <u>Three-Phase Unigrounded Y System</u>: From an interference point of view, at the fundamental frequency, the unigrounded Y system is similar to the delta system providing the above conditions of phase current balance and spatial dependency are satisfied. With the unigrounded Y system there is a neutral conductor providing a current return path but there is only a single ground connection at the originating point. All of the return current is, therefore, forced to return along the neutral conductor in the following manner. When the phase currents at the fundamental frequency are balanced in all three phases, the vector sum of the current in the neutral conductor is zero due to the 120 degree phase relationship.

7.321 At 180 Hertz (third harmonic) the maximum value is reached three times as often as the fundamental frequency. Thus when the fundamental has gone 120 degrees, the third harmonic has gone through 3 times 120 or 360 degrees. Therefore, at 180 Hertz, the currents in each phase conductor are in phase and the current in the neutral conductor is the sum of the currents in the phase wires and 180 degrees out of phase.

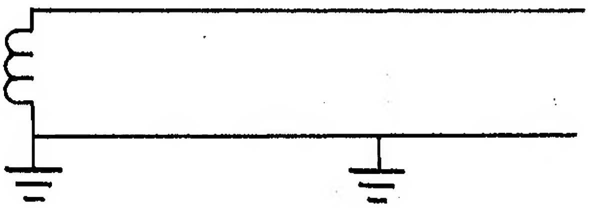
THREE-PHASE DELTA



THREE-PHASE UNIGROUNDED "Y"



THREE-PHASE MULTIGROUNDED "Y"



SINGLE-PHASE MUL

TYPES OF POWE

FIGURE

7.322 The fifth harmonic (300 Hz.) is 5 times 120 or 600 degrees out of phase. This is equivalent to 600 minus 360 or 240 degrees which corresponds to 120 degrees opposite the fundamental. If the currents in all three phases are equal the algebraic sum of the currents in the neutral conductors will be zero, as for the fundamental frequency. The seventh harmonic is also a balanced component like the fifth.

7.323 In the ninth harmonic (540 Hz.), the phases are 9 times 120 (3 x 360) or 1080 degrees apart and, therefore, in phase. Again, as with the third harmonic, the currents in each phase conductor are in phase and the current in the neutral conductor is the sum of the currents in the phase wires and 180 degrees out of phase.

7.324 Analysis of harmonic currents in a three-phase Y system reveals that all odd harmonic numbers which are divisible by 3 (3, 9, 15, etc.) are in phase in each of the phase conductors. Thus, the current in the neutral conductor is the sum of the currents in the phase wires and 180 degrees out of phase. These harmonics are often referred to as odd-triple harmonics (all odd-integers times 3). Odd harmonics which are not divisible by 3 (5, 7, 11, etc.) are either 120 or 240 degrees out of phase and act like balanced components. These harmonics have no effects on induction in balanced three-phase systems.

7.33 <u>Three-Phase Multigrounded Y System</u>: Three-phase multigrounded neutral (MGN) systems are the most commonly used for power distribution in the United States. Induction from MGN systems involves both the balanced and unbalanced currents previously discussed. Due to the multiple ground connections in these systems, the alternate path provided by the earth for the flow of current back to the source results in a potential interference problem even though 60 Hertz phase currents are well balanced. Since the odd-triple harmonics are adding in phase and some of the current is returning through the earth, induction at harmonic frequencies is of concern. The division of current between the neutral and earth-return circuits is dependent on the characteristics of the particular power system and its associated grounds. This would include but not be limited to the size of the neutral conductor and the earth resistivity in the area of the system. It is not unusual to find 60 percent or more of the current returning in the earth path and 40 percent or less in the neutral wire.

7.331 When the fundamental frequency current flowing in each phase of a three-phase system is equal to the others no 60 Hertz current will flow in the neutral conductor. The entire return current will flow in the other two phase wires as shown in Example 1.

<u>EXAMPLE 1</u>

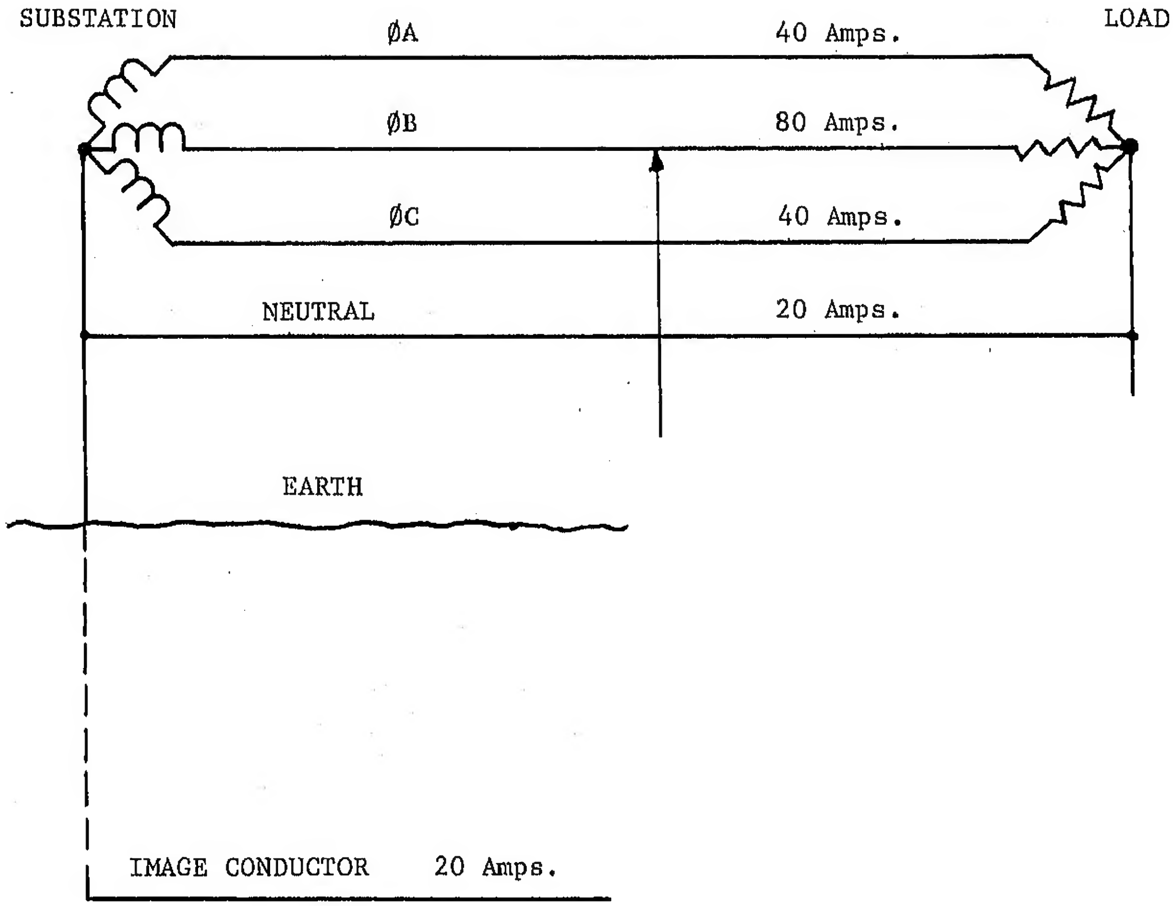
CONDUCTOR	CURRENT IN AMPERES
Phase A	40
Phase B	40
Phase C	40
Neutral	0
Ground	0

Under these conditions the magnetic field produced that would affect the telephone system would be small because each phase wire is close to the others so the magnetic fields cancel and there is no ground return current. It is not the current that flows along one phase wire and returns over the other phase wires that produces the magnetic field which has the greatest effect on telephone cable conductors.

7.332 The current that produces the magnetic field most seriously affecting cable conductors is the unbalance current between the three phases. This current is forced to return to the substation over the power neutral conductor and its associated earth path. (See Figure 16). Example 2 illustrates the relationship when phase to phase unbalance is present in the power system.

EXAMPLE 2

CONDUCTOR	CURRENT IN AMPERES
Phase A	40
Phase B	80
Phase C	40
Neutral	20
Ground	20



GROUND I
F:

The magnetic field produced under these conditions, that would affect the telephone system, would be much greater than in Example 1. This occurs because the conductors of Phases A, B, C and the neutral are in close proximity to each other (approximately two foot separation) and their magnetic fields ap proximately cancel. The 20 amperes of ground return current, however, is returning to the substation about 400 feet below the earth. This provides very little cancelling effect on the magnetic field produced by the associated 20 amperes flowing in Phase B.

7.4 Single-Phase Multigrounded System: The conditions with single-phas e multigrounded neutral systems is quite different. Harmonic cancellation which occurs in three-phase systems is absent. Thus, all harmonic currents, including the fundamental frequency, divide between the earth and neutral wire paths. This produces a potential for difficult interference problems. Two-Phase multigrounded systems are also unbalanced due to absence of the third phase.

7.5 Power System Harmonic Sources: A power system supplies 60 Hertz power to power users but it can also be a generator of harmonic frequencies. These harmonic frequencies, which are multiples of the fundamental frequency can originate from the following sources:

a. Distribution Transformers and Regulators
b. Power Factor Correction Capacitors (These do not themselves generate the harmonics. See Paragraph 7.521 for discussion of power line capacitor installations).
c. Rotating Machinery
d. Rectifiers
e. High Voltage DC Transmission Lines (Harmonics are generated in the rectifiers and inverters at each end of the line. See Paragraph 7.7).
f. Solid State Power Control Devices

7.51 Distribution Transformers: Distribution transformers are a source of harmonics due to the nonlinear characteristics of the core materials. Increasing the primary voltage to 10 percent above the rated value can increase inductive noise due to harmonic current output by 200 to 300 percent. Even when transformers are not over excited there is always some distortion of the fundamental wave shape but this is usually at a low level so that noise objectives can be met.

7.52 Power Factor Correction Capacitors: Power companies widely use capacitor banks for several reasons, which include:

a. Increasing voltage levels at loads.
b. Raising the power factor at inductive loads
c. Reducing the current and associated I^2R losses
d. Reducing circuit loading, making possible the addition of loads.

7.521 Distribution capacitor banks, unlike transformers, should not be suspected of generating harmonics. However, the flow of harmonic currents generated by other sources may be significantly altered by the presence of capacitors on the power system.

7.522 Sometimes the installation of a capacitor bank will result in a circuit approaching series resonance in the voice frequency pass band. When this occurs, there will be a low impedance to ground at those particular frequencies. Thus, a relatively low harmonic voltage can produce a comparatively high current in the power conductors. This can result in inductive interference in nearby telephone circuits.

7.6 Rotating Machinery: Deviations from perfection in the design and manufacture of generators can cause them to act as producers of harmonic frequencies. The wave shape of generators is one factor in the general problem of inductive coordination between power and communication circuits, but not a major one. Effective control of the wave shape of generators has been accomplished by cooperative efforts among manufacturers, power companies and telephone companies.

7.7 Rectifiers and Inverters: Harmonics appear on the dc side of a rectifier and on the ac side of an inverter. On the dc side of a rectifier the orders of the harmonics are even orders. On the ac side of an inverter there are two harmonics for each one on the dc side with orders of one less and one more than on the dc side. In a six phase line the fifth and seventh, eleventh and thirteenth, etc., are present on the ac side, with the sixth, twelfth, etc., on the dc side.

7.8 Solid State Power Control Devices: These customer owned devices are used for light, temperature, and heat control. Industrial applications include motor drive control and electric furnace control.

7.81 These devices are wired to function as fast action switches. Control of the load is accomplished by changing the proportion of the time that the load is energized. There are two basic ways loads are controlled by these devices, phase or "chopper-type" control and synchronous control.

7.811 Phase or "Chopper-Type" Control: This type connects the ac supply to the load during a fraction of each half Hertz of the supply's sinusoidal wave shape. Control time in each half Hertz that the device

7.812 Synchronous Control: This t instant the sinusoidal supp conduction for one or more complete H Control is accomplished by governing Synchronous control can be used only electrical space heating.

7.82 The constant switching on or "chopping" action of phase controlled devices causes harmonic distortion of the power system wave shape. The harmonic frequency spectrum of this distortion is so broad that effective filtering is difficult. Synchronous control avoids the distortion due to chopping.

7.83 Probability of inductive interference increases with the size of the controlled load. Loads of 10 kW or larger are likely to cause trouble in nearby communications circuits even though located near the substation. Loads as small as 3 kW may also cause telephone noise when they are at locations far from the substation.

8. SUSCEPTIBILITY

8.1 Susceptibility can be defined as those characteristics in the telephone system that determine the level of service impairment from a given longitudinal influence. They are usually expressed as the relationship between longitudinal voltage (and/or current) and metallic voltage (and/or current) that results from a given longitudinal influence.

8.2 Significant longitudinal impedance characteristics of a voice frequency subscriber loop are a relatively low impedance to ground at the central office end and a relatively high impedance to ground at the subscriber end. A longitudinal voltage induced on such a circuit will produce a significant voltage to ground at the subscriber end which will diminish to minimum value at the central office end as shown in Figure 17. Conversely, there is minimum longitudinal current flow to ground at the subscriber end and maximum at the central office.

8.3 A useful measure of the ability of the telephone system to prevent longitudinal/metallic conversion of voltages and currents is its overall degree of balance. This may be defined as:

$$\text{Circuit Balance (dB)} = 20 \log \frac{V_L}{V_M} \text{ or } PI - Nm$$

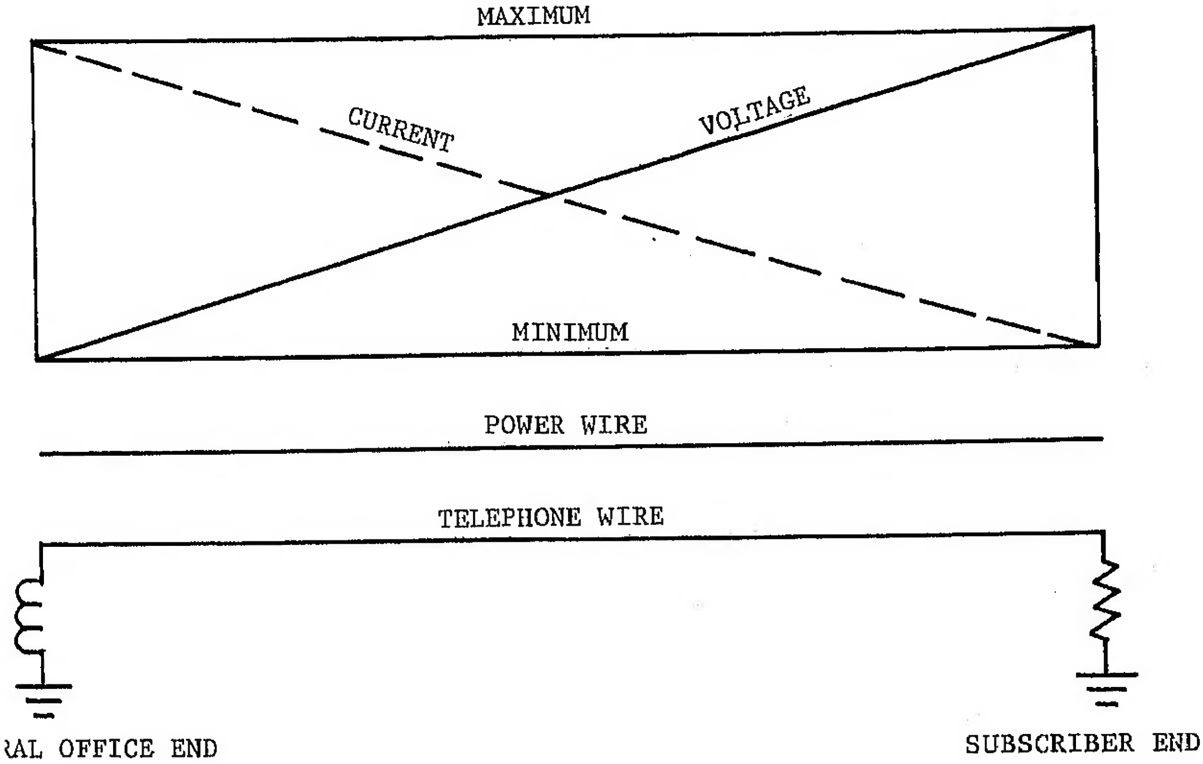
Where:

V_L is the average voltage-to-ground, at a particular frequency, measured on both conductors at the subscriber end of the system, with the CO end grounded.

V_M is the metallic voltage between the two conductors measured at the subscriber end of the system.

PI is the power influence, in dBrnc, measured at the subscriber end of the system.

Nm is the metallic noise, in dBrnc, measured at the subscriber end of the system.



DISTRIBUTION
LONGITUDINAL NOISE VOLTAGE AND CURRENT
SUBSCRIBER LOOP

FIGURE 17

8.31 Elements in the telephone system that can be important factors in system balance are shown below:

8.311 Impedance

(a) Central Office Equipme
including the line cir
electronic loop extend

(b) Drainage Units (where

(c) Telephone Set Ringers

(d) Some types of ANI (Aut
equipment station conn

8.312 <u>Series Resistance</u>

(a) Conductor Resistance

(b) Loading Coil or BTI (Bridged Tap Isolator)

(c) Splice Resistance

(d) Heat Coil Resistance (Where Used)

(e) Station Protector Fuse Resistance (Where Used)

(f) Carrier Filter Resistance (Where carrier is super imposed on voice frequency loops)

8.313 <u>Resistance-to-Ground (Admittance)</u>

(a) Cable insulation leakage

(b) Glass insulator leakage (open wire plant)

(c) Central Office Protectors

(d) Protector leakage (Station and other)

(e) Terminal block leakage

(f) High voltage protection device leakage

(g) Drainage unit leakage (Where Used)

(h) Cable capacitance unbalance to shield

8.32 In a perfectly balanced telephone circuit, longitudinal induced voltage will cause an equal flow of current to ground from each conductor. As a result, net metallic voltage from induction will be zero. For this to occur a circuit would have to meet the following requirements:

(a) The series impedances of both sides of the circuit are equal.

(b) The admittances of both sides to shield are equal.

(c) The impedances between both sides and any other telephone circuit in the same cable are equal.

8.4 In practical situations all three factors are present, each in differing magnitudes. There is always unbalance in the telephone system, influence from the power system and coupling between the two.

9. NOISE REFERENCE STANDARD

9.1 The objective in telephone circuit noise measurements is to characterize quantitatively the effects of noise on the listener such that two noises that are judged equally interfering are assigned the same numerical magnitude. To accomplish this, the noise measuring set (NMS) weighs the components of a given noise voltage in proportion to their interfering effect, adds the weighted components on a rss (power) basis, and indicates the result on a meter with suitable dynamic characteristics.

9.11 <u>Noise Reference Level (dBrn)</u>

9.12 The reference level for transmission measurements is one (1) milliwatt (10^{-3} watts) and is designated OdBm. The reference voltage is dependent on the impedance into which the one milliwatt is dissipated. For example, the reference voltage for OdBm into 600 ohms is 0.775 volts and into 900 ohms is 0.949 volts.

9.13 The reference level for noise measurements is one (1) picowatt (10^{-12} watts) of 1000 Hertz power. This is also 10^{-9} milliwatt (-90 dBm) and is designated OdBrn. A letter or number following dBrn refers to the weighting at which the measurement is made (eg. 25 dBrnc, 30 dBrn 3 kHz refers to "C" message or 3 kHz flat weighting).

9.14 At 1000 Hertz -90 dBm represents OdBrn. Zero dBm would, therefore, represent 90 dBrn. Minus 33 dBm at 1000 Hertz would be the same at 57 dBrn (90 - 33 = 57) on a NMS, -69 dBm would be 21 dBrn, etc.

9.15 The reference point for OdBrn on a NMS is the same for all weightings at 1000 Hertz. However, the reference voltage is dependent on the input impedance as shown in Table II.

TABLE II

VOLTAGE REFERENCE POINTS

NMS SETTING	VOLTAGE AT 1000 HZ. FOR OdBrn
Ng (Noise-to-ground)	2.45 m
BRDG	2[illegible]
600	[illegible]
900	

9.2 Frequency Weighting

9.21 Noise measuring sets incorporate C-Message Weighting which provides a standard characteristic for the measurement of telephone circuit noise. This is the present standard for exchange noise work. The sets also provide networks for measuring on program and special service circuits.

9.22 C-Message Weighting

The frequency characteristics of the C-Message Weighting are shown in Figure 18. This network, which is used for measurement of noise on message circuits, is very important since if reflects the amount of noise a subscriber actually hears. C-Message Weighting characteristics were determined by subjective tests and include the frequency response of a Western Electric 500 or equivalent type telephone set and hearing mechanism. Thus, use of C-Message Weighting in the measuring instrument provides a means of making an objective measurement to characterize a subjective response.

9.23 3 KHz Flat Weighting

The response of 3 KHz flat weighting is also given in Figure 18. This weighting removes nearly all attenuation in the range of 60 Hertz to 3 KHz, which is present in C-Message Weighting. Normally this measurement provides the level of the fundamental frequency (60 Hz.) only. This is on the assumption that the level of 60 Hertz is substantially higher than the harmonics and thus the presence of the harmonics does not substantially increase the 3 KHz flat reading. This weighting is normally used during noise investigations to determine the magnitude of fundamental frequency voltage.

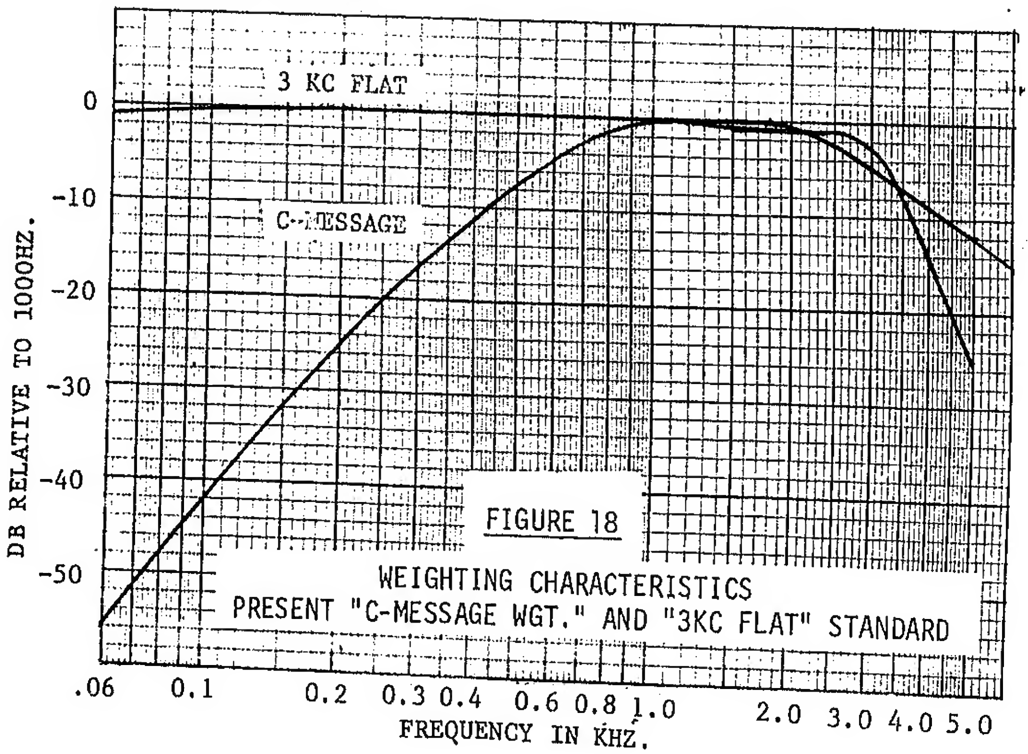


FIGURE 18

WEIGHTING CHARACTERISTICS
PRESENT "C-MESSAGE WGT." AND "3KC FLAT" STANDARD

9.24 Program Weighting

Program weighting is used for measurements of noise on program circuits with bandwidths up to about 8000 Hertz. Program weighting differs from message weighting in that the design of the weighting network takes into account the response of the program receiving equipment rather than the response of the telephone instrument.

9.25 15 KHz Flat Weighting

The 15 KHz flat weighting is used to measure noise on studio to transmitter program loops and on wired-music circuits. These circuits require flatter and wider bandwidths than regular program circuits.

10. COORDINATION

10.1 Line facilities of power and telephone systems are usually closely associated. Thus, problems of electrical interference can be created. The control of such interference involves the design, maintenance, and operating practices of both systems as well as the relative locations of both lines. In situations where standard designs and procedures will not prevent interference or keep it at a tolerable level, modifications on the part of one or both systems may be necessary. This will usually require coordinated engineering efforts for the best overall solution.

10.2 In 1945 the Joint General Committee of the Edison Electric Institute and the Bell System reissued three earlier reports covering the cooperative handling of electrical coordination problems. Two important points in these guides are:

(a) To meet public service needs, the solution of inductive interference problems in a mutual responsibility of the power and telephone companies.

(b) Carrying out this responsibility in an equitable and economical manner requires the establishment of cooperative arrangements between the utilities.

10.3 Many Public Utility Regulatory Commissions have issued orders concerning inductive coordination. These orders which have not been issued by all regulatory commissions and which vary considerably should be reviewed for each location involved. For the most part, such regulations specify the following:

(a) Cooperation to prevent or mitigate inductive interference problems.

(b) Advance notice of new construction, rearrangements or changes in operating procedures which cause inductive interference.

(c) Application of the principle of the least total cost in situations where there are several methods for mitigating or preventing inductive interference.

(d) Referral to the regulatory agency if parties cannot agree on a procedure for mitigating or preventing inductive interference.

10.4 Handling of Inductive Coordination Problems

Considerations toward developing improved relations between power and telephone companies include the following:

(a) A consistent method must be followed during investigation of noise problems to insure that the telephone company has a problem requiring power company assistance before any contact is made.

(b) Contacts with the other company should be made through designated personnel.

(c) All requests whether for information, participation or action should be followed up with written correspondence.

(d) Should action by the power company seem necessary to solve an interference problem, that company should be invited to participate in determining a proper solution rather than unilaterally proposing one.

(e) Persons designated as contacts with the power companies should know and understand the other company representatives point of view and be able to adequately present their own companies point of view.

(f) Supervisory persons from both companies should know each other and meet periodically to discuss matters of mutual concern.

(g) Requests and correspondence from the power company should receive prompt attention. All commitments must be met to avoid delays in construction or rearrangement work that requires coordination of forces from both organizations.

10.5 Most regulatory commissions require some form of cooperation between power and telephone companies and in varying degrees designate how it is to be carried out. Mutual cooperative effort could preclude additional regulations that might be less desirable and less flexible for all.

10.6 Principles for Inductive Coordination

The general principles for inductive coordination that follow are given as a guide for establishing satisfactory relations between power and telephone companies.

10.61 Mutual Responsibility: Power and telephone companies are public utilities supplying essential public services. There is a mutual responsibility to cooperate in preventing and mitigating interference in the services provided.

10.62 Cooperation: Each company should notify the other in advance of planned construction or changes in operating conditions which might require inductive coordination.

10.63 Coordination Methods: These methods should include, as far as practical, limiting the inductive influence of the power facility, the susceptibility of the telephone facilities, and the coupling between them. Where such methods prove inadequate, specific coordination methods should be applied to facilities of either or both to reduce interference to an acceptable level.

10.64 Coordinated Locations for Facilities: Joint utilization of highways, rights-of-way, trenches and structures is usually the most economical and efficient way of extending and maintaining power and telephone facilities. Planning of major facilities should be coordinated to keep inductive exposure to a minimum.

10.65 Specific Coordination Methods: Where specific coordination methods are required, the best engineering solution should be adopted by applying the following principles:

(a) Specific methods should meet the service requirements of both systems in the most convenient and economical manner without regard to whether they apply to power or telephone systems or both.

(b) All factors should be considered for all facilities involved. These include both current factors and those that might be required for foreseeable future conditions.

(c) In determining specific methods to be adopted, neither company should judge the service requirements of the other system, or what constitutes good practice in that system.

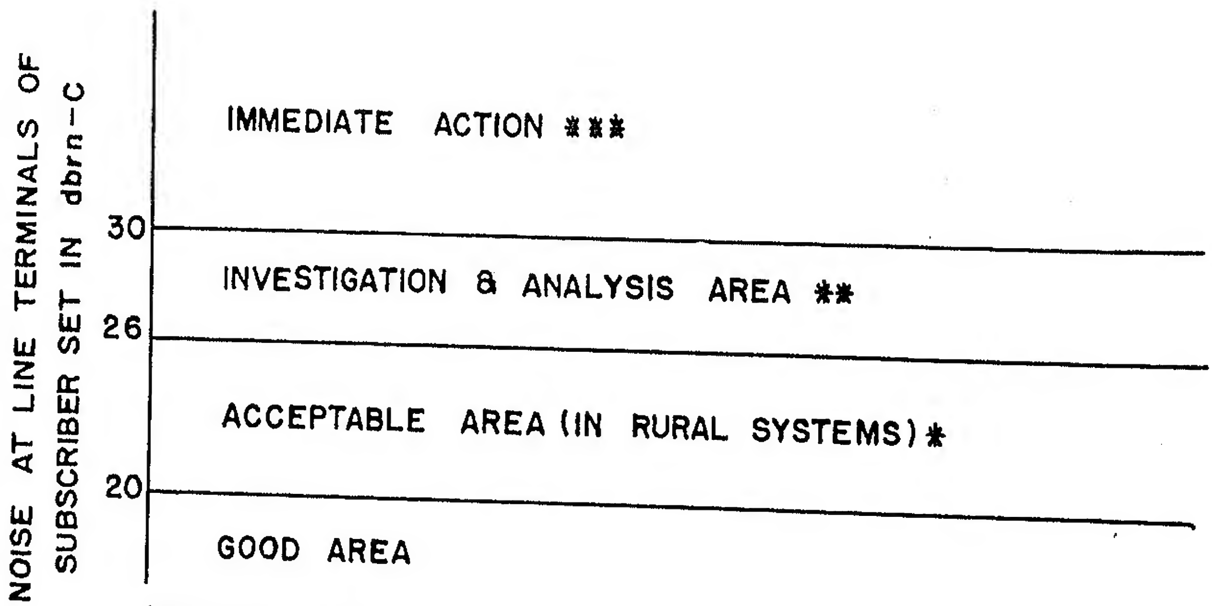
10.66 Deferred Coordination: Conformance to general coordination methods might be deferred, if economically advantageous, on existing or new facilities of one company when such facilities are alone. Conformance should be applied when development of facilities by the other

company creates a problem. Where existing facilities of either company do not conform to general coordination methods, conformance should be applied upon identification of the need by either party.

11. NOISE OBJECTIVES

11.1 Provision of high quality telephone service dictates that subscribers receive more and better services as the technological state of the art permits. This includes, of course, better transmission and quieter circuits. For this reason both transmission and noise objectives are always under study and subject to reevaluation and improvement. Current REA noise objectives for subscriber loops and trunk for steady state noise are given in REA TE&CM Section 415.

11.2 Figure 19 gives the noise maintenance limits for steady state noise for subscriber loops. The acceptable, marginal, investigation and analysis, and immediate action areas are clearly shown.



*Marginal in Urban Areas

**Marginal in all areas

***Cause for concern. Corrective action should be taken.

SUBSCRIBER LOOP NOISE MAINTENANCE LIMITS

FIGURE 19

11.3 Measurements for establishing the magnitude of and isolation of circuit noise are shown in TE&CM 451.1. Procedures for investigation of noise problems are discussed in Paragraph 12 & 13.

12. INTERPRETATION OF NOISE MEASUREMENT DATA

12.1 As indicated previously in Paragraph 9, noise measurements are made in dBrnc which assigns a quantitative value to the noise on a telephone line, giving a different weight to each frequency component (harmonics of 60 Hertz). C-message weighting is the present standard for noise work in the United States. The two most frequently used measurements of dBrnc are circuit noise (metallic) and power influence. Circuit noise is that across the metallic pair and is the noise heard by the subscriber. Power influence measurement in effect connects the two wires of the metallic pair together and measures the dBrnc to ground.

12.11 All noise measuring sets measure the voltage-to-ground in the same manner via a voltage divider which attenuates the signal 40 dB. Some sets have a scale calibration which requires adding 40dB to the reading to obtain the actual value of the level measured. Scales of other sets are calibrated so this 40dB attenuation has been taken into account and the actual level can be read directly without adding the 40 dB. Since balance should be derived from the value which includes the 40 dB correction care must be taken to know the scale calibration for the noise measuring set being used.

12.12 The terms Noise-to-Ground (Ng) and Power Influence (PI) have usually been considered synonomous when making measurements regardless of the type set used. Some confusion can be avoided by applying the term Noise-to-Ground to readings obtained when using sets requiring the addition of 40 dB and Power Influence when using sets which do not require the addition. When thought of in this manner Noise-to-Ground may be converted to Power Influence, which is used to calculate balance, by adding 40 dB (PI = NL + 40).

12.13 A third measurement is called Noise Longitudinal. This measurement can be made only with the isolation or termination set of the type shown in TE & CM Section 451.1. It is the measurement of noise in dBrnc across a resistor in the longitudinal path of a center tapped coil. The short circuited tip and ring conductors are connected to the center tap of the coil through the resistor. This resistor has a value of 1/100 the impedance of the noise measuring set. Thus, it is necessary to add 40dB to the results of this measurement to derive the Power Influence (PI=NL + 40).

12.131 This method is valuable when measuring in the vicinity of a low impendance to ground such as near the central office. Longitudinal current and voltage levels along a subscriber loop are discussed in paragraph 8. From this it can be seen that at some point along the cable measured value of Noise Longitudinal will be the same as that of Noise-to-Ground. At the subscriber location the Noise-to-Ground will be much higher than Noise Longitudinal while near the office the reverse will be true.

12.132 Even though 40 dB is added to both Ng and NL to obtain PI it cannot be stated that Ng = NL for one is a measurement of Longitudinal voltage to ground and the other is a measurement of longitudinal current flow. Both measurements should be made at each location and the highest value used to calculate balance.

12.2 Subscriber tolerance to various dBrnc levels varies widely. For a typical subscriber, a line with 20 dBrnc of noise will be rated good or better. It has also been established that loop noise in excess of 30 dBrnc is totally unacceptable and immediate action should be taken to reduce the noise. Values between 20 and 26 dBrnc are considered marginal in urban areas and some action toward improvement is indicated. For long rural oops, 20-26 dBrnc is considered acceptable and 26-30 dBrnc marginal provided it does not result in subscriber complaints.

12.3 Poor telephone circuit balance, high influence from the power system or a combination of both can contribute to subscriber noise. Results of noise measurements can be used to determine circuit balance. This can be used to determine whether telephone system balance or power system influence are controlling. On a subscriber loop, "Noise Metallic" and "Power Influence" are measured at the subscribers location. For trunk circuits, the same measurements are made at the central office(s). Since the measurement at the central office is near a low impedance to ground, "Noise Longitudinal" should be measured and converted to "Power Influence" for computation of balance.

Telephone circuit balance is determined by taking the difference between the measured power influence and noise metallic values in dBrnc. (PI - Nm = dB Balance).

12.31 The accepted method for determining the longitudinal balance of various components in the telephone network is to inject a balanced longitudinal signal on the tip and ring conductors and measure the magnitude of that signal that has been converted to a metallic signal across the tip and ring conductors. The balance in dB is then computed as follows:

$$\text{dB Balance} = 20 \log \frac{V_g}{Vm}$$

Where: V_g = The magnitude of generated signal in volts.

Vm = The magnitude of the metallic signal in volts.

Overall circuit balance in the field may be determined from the results of noise measurements. The longitudinal induced voltage from the power system (Power Influence) is used in lieu of an oscillator derived signal. The dB Balance is equal to Power Influence (PI) less the Circuit Noise (Nm). dB Balance = PI - Nm.

12.32 Circuit balance will be accurate only to the extent that the metallic noise results from the conversion of the longitudinal induction to metallic signals. Should there be other dominant metallic noise sources, such as that originating in the central office battery or carbon transmitter of a station, accurate balance measurements may not be possible. Experience has indicated that, where the power influence is greater than 60 dBrnc and the noise contribution of the carbon transmitter is eliminated through use of passive termination, the metallic noise will generally be the result of longitudinal-to-metallic conversion and accurate balance computations can be made.

12.33 The degree of telephone line balance can be determined from Table III below:

TABLE III

TELEPHONE LINE BALANCE

COMPUTED BALANCE (dB)	(SUSCEPTIVENESS) GRADE OF BALANCE
50 or below	Poor
50 to 60	Marginal
60 to 70	Good
70 and greater	Excellent

12.4 Two other factors are important in the investigation of noise problems. One is the potential of the power system for generating an interference environment and the other is the degree of coupling between the power and telephone lines. A measure of both is indicated by the magnitude of power influence measurements. Unacceptable circuit noise levels can occur with marginal power influence if Telephone line balance is less than excellent. The degree of these factors can be determined from Table IV below:

TABLE IV

POWER LINE INFL

POWER INFLUENCE IN dBrnc
80 or below
80 to 90
90 and Over

12.5 Changes in power load during the c
influence levels with a resulting
noise, even though at the time measurement
and circuit noise levels are acceptable.
it would be advisable to repeat the measu
power demand.

12.6 In addition to the applications discussed in paragraph 12.3 and 12.4 above, "Noise-to-Ground" is also useful for determining the magnitude of low frequency induction. In determining these voltages the "Noise-to-Ground" is measured and converted to power influence as shown in paragraph 12.11. The open circuit voltage may then be found in Table V. When a noise measuring set having 3kHz weighting is not available ac voltage from tip to ground and ring to ground may be measured with a good volt-ohmeter. CAUTION: When measuring voltage to ground in this manner a meter with dc blocking must be used to avoid errors in measurement.

12.7 Preliminary Analysis of Data: Information obtained during preliminary measurements may be used as a broad diagnostic tool. Review of this data may point to a potential trouble source or to indicate the direction subsequent investigation should take. Following is a list of key points which should help determine the course of further work.

(a) Power influence (3 KHz Flat) is greater than 126 dBrn: The 50-volt induced ac guideline is exceeded; (see REA TE&CM Section 825); work with power people to reduce influence. (See paragraph 15)

(b) Power Influence, (C-message) is greater than 90 dBrnc: Circuit noise objectives would be exceeded even with superior plant balance; first, work to reduce coupling by improving telephone plant shielding and, if unsuccessful, to reduce influence of the power system.

(c) Power influence, (C-message) is greater than 80 dBrnc: Circuit noise objectives could be exceeded with good plant balance; work to reduce coupling by improving telephone plant shielding.

(d) Power Influence, (C-message) is less than 80 dBrnc: Circuit noise objectives would not be exceeded with good plant balance, work to improve balance.

(e) Balance, (C-message) is less than 60 dB: Work to improve balance. Apply isolation techniques (see paragraph 13.4) to locate unbalance.

(f) One Kilohertz loss is 3 dB greater than estimated: Work on cable to determine cause of transmission degradation before proceeding further with noise investigation.

(g) DC Loop Current less than 20 mA: Investigate cause prior to continuing noise investigation.

Values shown above are broad guidelines and should not be considered as absolute figures for application to all cases.

TABLE V
CONVERSION CHART
POWER INFLUENCE READINGS (3khz Flat)*
TO OPEN CIRCUIT VOLTAGE

dB	Open Circuit Volts	dB	Open Circuit Volts	dB	Open Circuit Volts	dB	Open Circuit Volts	dB	Open Circuit Volts
90.5	.8207	100.5	2.595	110.5	8.207	120.5	25.95	130.5	82.07
91.0	.8693	101.0	2.749	111.0	8.693	121.0	27.49	131.0	86.93
91.5	.9208	101.5	2.912	111.5	9.208	121.5	29.12	131.5	92.08
92.0	.9754	102.0	3.084	112.0	9.754	122.0	30.84	132.0	97.54
92.5	1.033	102.5	3.267	112.5	10.33	122.5	32.67	132.5	103.3
93.0	1.094	103.0	3.461	113.0	10.94	123.0	34.61	133.0	109.4
93.5	1.159	103.5	3.666	113.5	11.59	123.5	36.66	133.5	115.9
94.0	1.228	104.0	3.883	114.0	12.28	124.0	38.83	134.0	122.8
94.5	1.301	104.5	4.113	114.5	13.01	124.5	41.13	134.5	130.1
95.0	1.378	105.0	4.357	115.0	13.78	125.0	43.57	135.0	137.8
95.5	1.459	105.5	4.615	115.5	14.59	125.5	46.15	135.5	145.9
96.0	1.546	106.0	4.888	116.0	15.46	126.0	48.83	136.0	154.6
96.5	1.637	106.5	5.178	116.5	16.37	126.5	51.78	136.5	163.7
97.0	1.734	107.0	5.485	117.0	17.34	127.0	54.85	137.0	173.4
97.5	1.837	107.5	5.810	117.5	18.37	127.5	58.10	137.5	183.7
98.0	1.946	108.0	6.154	118.0	19.46	128.0	61.54	138.0	194.6
98.5	2.061	108.5	6.519	118.5	20.61	128.5	65.19	138.5	206.1
99.0	2.184	109.0	6.905	119.0	21.84	129.0	69.05	139.0	218.4
99.5	2.313	109.5	7.314	119.5	23.13	129.5	73.14	139.5	231.3
100.0	2.450	110.0	7.748	120.0	24.50	130.0	77.48	140.0	245.0

*Power Influence = Noise-To-Ground + 40dB

13. CONTINUATION OF INVESTIGATION

13.1 When results of the preliminary measurements are greater than the levels suggested in paragraph 12.6 alternative investigation procedures should be followed. There is a good possibility that many noise problems can be solved by either reducing the effective coupling by shielding or reducing the susceptiveness by improving the balance of the facility. Experience has shown that where the power influence is less than 80 dBrnc the investigation should concentrate on improving the balance. When the power influence exceeds 80 dBrnc the investigation should first be directed toward determining shield effectiveness and whether shielding might be improved to reduce effective coupling.

13.2 Many noise problems result from combinations of contributing factors at several locations along the telephone circuit. These should be located and corrected individually.

13.3 Methods for determining shield effectiveness are presented in TE&CM Section 451.2. Discussion of test procedures for isolating and locating various types of shielding problems is included. Shielding problems, both open and high resistance connections, have been found to be a major factor during noise investigations.

13.4 Procedures for isolating the source of circuit unbalances are shown in TE&CM Section 451.1. Two methods are discussed, one for use with working circuits and the other for use with idle cable pairs.

13.5 A noise problem may persist even after the coupling has been reduced to its lowest possible level by improving shielding in the telephone system and balance has been improved to the highest possible level. This will usually occur when power influence is in the high range (greater than 90 dBrnc). In such cases, it is helpful to look at the power system in the area to perhaps locate factors contributing to the noise problem. Suggested methods are discussed in TE&CM Section 452, together with data which can be given the power company to support a request for joint coordination.

14. SOURCES OF TELEPHONE SYSTEM UNBALANCE

14.1 When interpretation of data indicates telephone system unbalance is a factor, the following general sources of unbalance should be considered.

14.11 Unbalance in the battery feed circuits in the central office equipment for subscriber or trunk circuits.

12 Unbalance in electronic equipment installed in the central office such as voice frequency repeaters, loop extenders, signaling sets,

14.13 Unbalanced cable pairs or open wire lines resulting from series resistance unbalance.

14.14 Unbalanced cable pairs or open wire lines due to shunt unbalance, insulation leakage or capacitance-to-ground unbalance.

14.15 Unbalance due to some types of party line identification methods.

14.16 Unbalance resulting from split cable pairs.

14.17 Unbalance station installations due to wiring errors.

14.18 Unbalance due to divided ringing.

14.19 Unbalance due to foreign attachments.

14.20 Unbalance due to foreign materials in ready access terminals.

14.21 Unbalance due to defective drop wires in aerial cable.

14.2 A checklist of potential noise sources in the various parts of the telephone system is included in Appendix B.

15. MITIGATION

15.01 Mitigation is the last resort in solving noise problems. It is not problem free and usually requires additional expense. Such procedures also change the characteristics of the plant to which applied. Although this is the least desirable means of reducing telephone system noise, it is the most attractive, since it can be applied selectively after a problem has been identified.

15.02 Major risks in elimination of noise problems by this method are:

(a) Creation of a new problem while eliminating another.

(b) Addition of a component to the system that reduces reliability and increases maintenance.

(c) Addition of devices requiring additional training due to the uniqueness of the sc

(d) Creation of added expense related to adn of potential problems resulting from adc components.

15.03 Noise Mitigation - Telephone

Procedures for minimizing susceptibility of t will be presented first. These methods shou: after all other possibilities have been exhausted.

15.04 Resistance Unbalance: Some noise problems are caused by series unbalances in the metallic pair or central office termination. These problems can sometimes be minimized by making tip and ring reversals along the metallic pair at appropriate location(s) to reduce the series unbalance at critical points.

15.041 This action should be attempted only when it has been established conclusively that the series (resistance) unbalance is a major factor in the noise problem. A simple unbalance measurement of overall resistance unbalance will not always establish this fact.

15.042 As discussed in paragraph 8 the induced voltage on the normal subscriber loop will be highest at the subscriber end and lowest at the central office. Conversely, the current resulting from induced voltage will be lowest at the subscriber end and highest at the office. The longitudinal to metallic conversion due to series unbalance is a function of the longitudinal current. Thus, a relatively high unbalance near the subscriber location may be resulting in minimal noise while a smaller one ear the office will produce high noise.

15.043 It is also possible that a series unbalance near the central office will be offset by unbalance on the other side of the pair in the remainder of the cable. The overall subscriber loop would then have a very small overall series unbalance and yet the major factor contributing to the noise would be the series unbalance.

15.044 Before making tip and ring reversals, the resistance unbalance of the cable should be measured section by section. Loading coil section lengths are convenient for this purpose. Not only is the magnitude of the unbalance important but also the side of the line (tip or ring).

15.045 When points are found where the magnitude of the unbalances are nearly the same in both directions for approximately the same cable length and they are on the same side (tip and ring) reversal should be considered. For example, measuring from a loading point 6 ohms is found in one direction to the next loading point and 5 ohms to the next loading point in the other, both on the ring side. Reversal of tip and ring at the middle load point will result in a one ohm series unbalance between the two outboard load points.

15.046 Where divided ringing is used and tip and ring reversal is made a second one should be made at each subscriber drop connection to insure proper ringing. In lieu of this a second reversal can be made in the main cable before the connection of the subscribers drop.

15.05 Capacitance Unbalance: Many noise problems are the result of shunt unbalances in the metallic pair. These problems can also sometimes be effectively minimized by making tip and ring reversals at appropriate location(s) along the metallic pair to reduce the effective shunt unbalance at critical points.

15.051 This corrective action should only be attempted when it has been established that shunt unbalance is a major vactor in the noise problem. This will usually be determined during noise isolation measurement combined with resistance unbalance measurements. Measurement of the pair capacitance unbalance to shield would be a more precise method of determining whether it is or is not a factor. Equipment for such measurements is quite expensive and the proposed procedure has been proven to produce good results.

15.052 As discussed in paragraph 8 on the normal subscriber loop, induced voltage will be highest at the subscriber end and lowest at the central office. Longitudinal to metallic conversion due to shunt unbalance is a function of the longitudinal voltage. Thus, a relatively high capacitance to shield unbalance near the central office will result in minimal noise while a smaller one near the subscriber will produce significant noise.

15.053 Locating points for tip and ring reversals can be accomplished during noise isolation measurements. When the circuit noise and/or balance is approximately the same in both directions (toward CO and subscriber) a tip and ring reversal can be considered. It is a good practice to verify that the unbalances are both on the same side of the pair (tip or ring) with a capacitance decade. This technique is discussed in TE&CM Section 451.3.

15.054 Where divided ringing is used and a tip and ring reversal is made, a second one should be made at each subscriber drop connection beyond the point of reversal to insure proper ringing. In lieu of this, a second reversal can be made in the main cable before the subscriber drop connection.

15.06 Longitudinal Chokes: As previously stated, some noise problems are caused by series (resistance) unbalances. These may occur either in the wire pair or central office termination. Such problems may be effectively minimized by installing a choke to reduce the longitudinal current. (See TE&CM Section 451.4)

15.061 A longitudinal choke is a two-winding mutually coupled well-balanced transformer. It is connected in series with the tip and ring conductor and poled to present a high longitudinal impedance while only adding the dc resistance of the windings to the metallic circuit.

15.062 Longitudinal chokes should be installed at the central office since they require a current flow for effective operation. They can be quite effective in reducing longitudinal harmonics that fall within the voice frequency band. The effective reduction in longitudinal current is less at lower frequencies. The may also be used at PBX locations and other field locations where there is a low impedance path to ground so enough exciting current will flow.

15.063 Sometimes a resonant condition will occur between the inductor and the capacitance to ground. When this happens the current may increase at some particular frequency.

15.064 Consideration should also be given to the effect of the choke on ringing frequencies. Where divided ringing is used the choke can cause cross-ringing at the higher ringing frequencies. Effects on other transmission characteristics should also be taken into account.

15.065 The high longitudinal impedance presented by the choke can sometimes create a new problem in lieu of the original. The voltage-to-ground will be elevated at the field side of the device. Thus, if there is a high capacitance unbalance to shield existing near the office, it may now become a major factor in continued high level noise on the circuit. Such a condition rarely occurs.

15.07 Neutralizing Transformers: A neutralizing transformer is another form of longitudinal choke. It effectively reduces both longitudinal voltage and longitudinal currents in telephone systems. (See TE&CM Section 451.5)

15.071 Multi winding neutralizing transformers are constructed by winding an ordinary telephone cable on a ferromagnetic core. This cable can be several hundred feet long and the number of pairs, for practical design purposes, range from 6 to 100 pair units.

15.072 Any one pair in the cable may be utilized as a primary winding with all other pairs as secondary windings. In some cases, a separate primary winding is provided to increase the dielectric of the transformer and its efficiency.

15.073 Operation of the neutralizing transformer is similar to the shield discussed in Paragraph 5. The turns ratio of the transformer is one-to-one with a very high self-inductance due to the iron core. Coupling between windings has very low leakage.

15.074 Voltage induced in the secondary windings, as with the cable shield, due to completion of the primary circuit by grounding is a function of the primary current (Ip) times the mutual impedance between the primary winding and the secondary windings. The phase of voltage induced in the cable pairs by the transformer action is in the opposite direction to that induced by the power system. Ideally, complete cancellation would occur, but in practical applications, as with cable shields, it will be incomplete. This is due to internal and external dissipative voltage drops of the primary. These are the dc resistance of the winding, the cable pair resistance which connects to the primary and the grounding resistances.

15.075 Neutralizing transformers haven proven to be effective in reduction of fundamental frequency longitudinal voltage by as much as 90 percent. It is equally as effective in reduction of 60 hertz harmonics provided the harmonic current flows in the primary circuit.

15.0751 When the primary circuit is long and the harmonic frequency is high, it is likely that capacitance-to-ground of cable pair forming the primary circuit would also provide a path for the harmonic current. This would render the transformers less effective in neutralizing those frequencies.

15.0752 Capacitance-to-ground of all the pairs may provide exciting current if no primary pair is available. Performance of the transformer will be slightly degraded in this mode of operation, but it is sometimes used.

15.076 As with any foreign device connected into the telephone system, the neutralizing transformer cannot be used without creating a potential problem. Some of these are discussed below. They should be used discriminately after all factors have been considered.

15.0761 All cable pairs connected through the neutralizing transformer are closely coupled. Thus, a problem on one pair can affect all pairs. For example, a grounded protector on one pair will cause the transformer to reflect a shorted turn which will nullify the neutralization. This will raise the longitudinal voltage on the other pairs.

15.0762 Neutralizing transformers may require lightning protection which might increase maintenance costs.

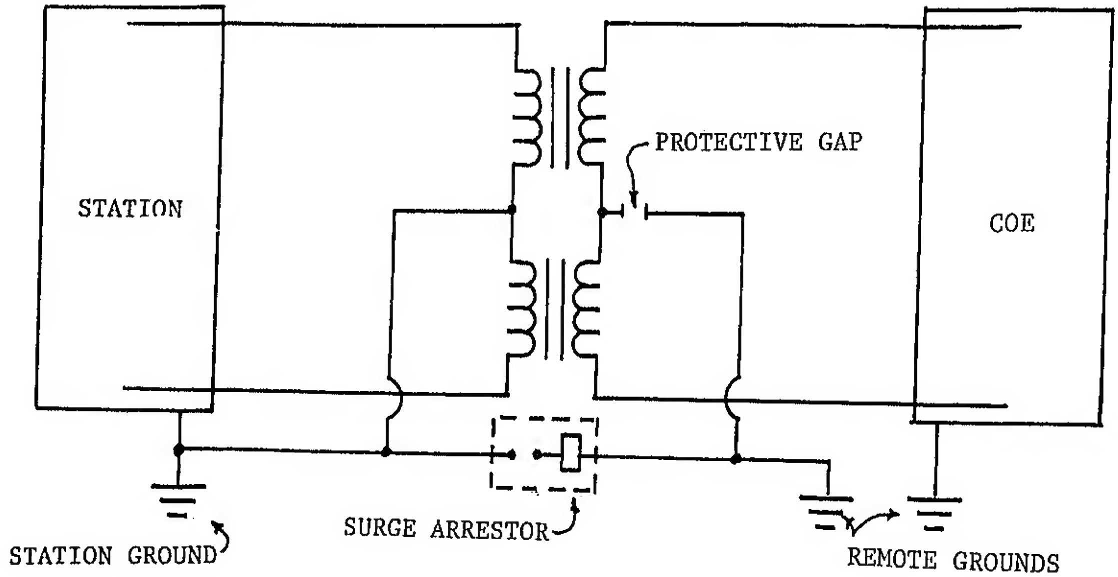
15.0763 Additional length of cable provided by the transformer windings may be sufficient to require relocation of load coils. The metallic impedance of a cable pair is altered only by the additional dc resistance and capacitance of the added cable length. Inductance added by the transformer is confined to the longitudinal circuit and does not affect the metallic circuit.

15.077 Neutralizing transformers are usually installed to reduce induced fundamental frequency voltage on the cable pairs. It can also reduce the voltage levels at harmonic frequencies on these cable pairs. Analog carrier systems can be operated through a neutralizing transformer. There is some additional insertion loss which must be considered when determining repeater locations for the carrier system.

15.0771 PCM carrier systems cannot be operated with voice grade neutralizing transformers. There is a PCM carrier system neutralizing transformer available which might be used where such systems exist. REA has not had operating experience at the time of this writing with these devices. Thus potential problems are unknown. There is a significant loss through the transformer at PCM carrier frequencies which must be considered when designing span line repeater spacings.

15.08 <u>Isolation Trasformers</u>: An isolation transformer presents a better way of reducing longitudinal current by interrupting the longitudinal circuit. This method, while effective, has a serious disadvantage. The characteristics of the telephone plant are changed and dc continuity is interrupted.

15.081 A schematic diagram of an isolating transformer is shown in Figure 20.



ISOLATION TRANSFORMER

FIGURE 20

15.082 This method is normally used for application on circuits that do not require dc for supervision. Among these are locally powered carrier systems and various telementry systems.

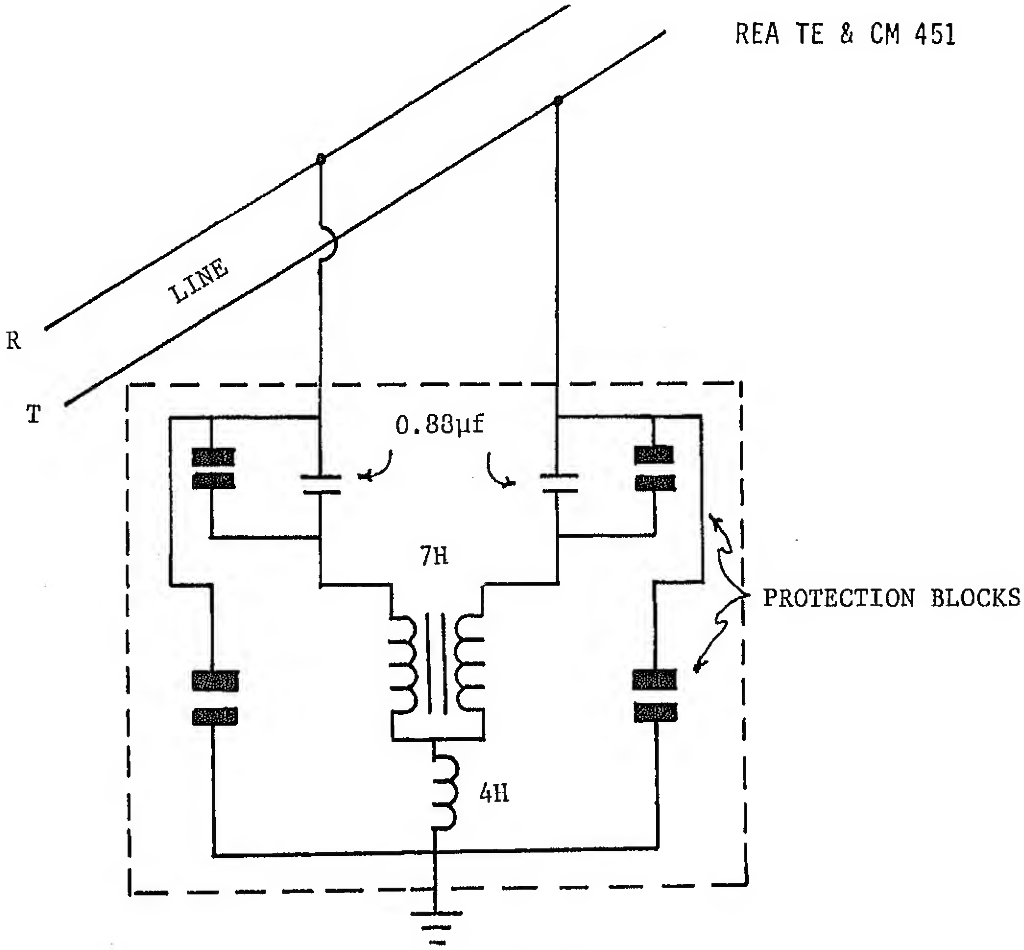
15.09 Drainage Reactors: Drainage reactors were originally designed to reduce electric field induced voltages on open-wire lines. Since electric coupling is usually high impedance, the impedance of the drainage unit can be fairly high and still produce good results.

15.091 Where magnetic induction is involved, the impedance of the drainage unit must be low compared with the circuit longitudinal impedance. This must be considered when thinking about applying a drainage unit as a mitigative measure.

15.092 A drainage reactor is two-winding well-balanced coil having a high mutual impendance between windings. An equal, but opposite, current flow in the two windings will result in cancellation of the coils longitudinal impedance. Thus, a low impedance path is provided from each side of the line (tip and ring) to the grounded midpoint as shown in Figure 21.

15.0921 Well balanced capacitors are used in series with each winding to prevent completion of the dc circuit across the line. Tuning drainage reactors are used with a system of capacitors and inductors arranged to provide a resonant circuit (usually at 60 Hertz) to ground.

15.0922 Drainage units composed of resistance and capacitance only were used before development of inductance and capacitance types used today.



108A, B or C DRAINAGE UNIT
INDUCTANCE CAPACITANCE TYPE

FIGURE 21

15.0923 Early types of drainage reactors with inductance and capacitance configuration (such as the W.E. 108A) caused high insertion loss at carrier frequencies. This problem was eliminated with the development of the W.E. 108B type.

15.093 Impedance to ground of a central office line circuit is approximately 100 ohms. If a drainage reactor installed at the CO is to effectively reduce the longitudinal voltage, its impedance must be low with respect to 100 ohms. When the need for series capacitance (which must be small to avoid signaling problems) in the drainage reactor is considered their application at the central office is not attractive.

15.094 Application of drainage reactors at or near the subscriber locations produces another set of potential problems. The longitudinal impedance of the station is high and the drainage device will effectively reduce the magnitude of longitudinal voltage.

15.0941 With the longitudinal voltage reduction, there will be an increase of the longitudinal current of the circuit. Thus, if there are any series unbalances existing in the telephone system near the subscriber location, an increase in noise may result.

15.0942 Where high frequency ringers (54, 60 or 66 Hertz) are used with divided ringing systems performance may be degraded where drainage reactors are installed.

15.0943 Another problem associated with drainage reactors is saturation. High longitudinal current may saturate the inductor and cause harmonic generation within the reactor. Thus, the reactor could reduce a problem such as gas tube firing while producing another in the form of audible noise.

15.095 Open wire plant is being phased out in the telephone industry. As this occurs there will be less use of drainage reactors for noise mitigation.

15.10 Ringer Isolators: Divided ringing and noisy telephone circuits go hand in hand. Where divided ringing is used, the unbalance of the station set due to a grounded ringer is a major factor in noise problems. Noise problems can occur even though high impedance ringers are used. Installation of a ringer isolator will produce a significant reduction in circuit noise.

15.101 Usually a ringer isolator cannot be used with two-party ANI systems where the tip-party identification is accomplished by detection of ground through a modified ringer. With the isolator in the circuit there is no path to ground unless ringing voltage is present.

15.102 There are devices available which combine a ringer isolator with an ANI detection device. These devices are not compatible with all metallic ANI detection systems.

15.11 Noise Mitigation - Power System

There are measures which may be applied by the power company for reduction of interference from power systems. Usually, a design which will minimize interference will also result in degradation of some other power system characteristics. Thus, reduction of interference is apt to be costly and otherwise unattractive to the power company. The truly optimal solution to an interference problem is one which results in the least cost and other disadvantages to both the power and telephone companies. Folowing are some possible power system procedures which might help achieve an optimum solution.

15.12 Load Balance: A method which can be applied to three-phase multi-grounded neutral systems is distributing the loads among the three phases so that the fundamental frequency currents of the phases are well-balanced along the entire length of the exposure. This would theoretically result in only the odd-triple harmonics appearing as residual current.

15.121 From a practical standpoint actually achieving a continuous phase balance is difficult. Utilization time for the various power system loads will rarely coincide and there is continuous change in overall loading throughout any given period.

15.122 A simple rearrangement of loads may prove beneficial at the time of completion. Three is no assurance that the loads may not shift in the near future and the interference return. Precise balancing of peak loads of the three phases at the substation will likely prove inadequate since loads on particular exposures within the power system may not coincide with the peaks at the substation.

15.13 Improved Neutral: Use of an additional or larger neutral is another possible method for interference reduction. This results in more residual current returning through the neutral rather than the earth. Additional cost to the power company should be compared to costs of other alternative solutions before application of this or any other method for interference reduction.

15.14 Capacitor Banks: When capacitor banks are found to be a factor, a possible solution is to relocate them to another position along the power line preferably nearer to the power substation. This can often result in a substantial reduction of harmonic magnitude. It can sometimes also shift the power system resonant frequency to a different value. If the point of relocation is to a point close to the substation the length of exposure to harmonic currents will be reduced even though resonances still exist and induced longitudinal voltages on telephone circuits will be below objective levels. Another possible disadvantage with relocation is that the capacitors might be less effective in the power system at the new location.

15.141 Grounded Y capacitor banks provide a low impedance path to ground for harmonics thus increasing the residual harmonics. A possible remedy is to "float" the banks (disconnect the ground) or to reconnect the banks in delta configuration.

15.142 With delta connection, the capacitors must withstand a higher voltage (phase to phase) than with Y connection (phase to ground). This makes them more expensive.

15.143 "Floating Y" connections are considered inferior to grounded Y connections for the following reasons:

(a) Neutral voltage under unbalanced conditior shifts with floating Y connection and neutral-to-ground ins is needed.

(b) Grounded Y connections are easier and less to fuse.

(c) Floating Y connections can produce seriou voltages, or phase reversals when one phase is open feed phase-to-ground loads at half voltage.

(d) There is a serious safety problem with floating Y connections. When a phase is open maintenance personnel may assume it to be dead while it is energized through the floating capacitor bank.

(e) Grounded Y connections provide a path to ground for surges.

15.144 A resonant shunt may be installed in the neutral connection of the capacitor bank between the tie point of the capacitors and ground. Inductance is added to lower the resonant frequency value to one which will induce less interference in the telephone systems.

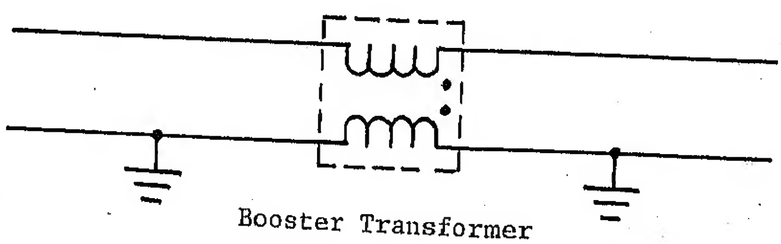
15.145 There are some low voltage distribution systems that use floating capacitor banks to minimize power system interference. When adequate safeguards are provided to prevent serious power system problems and to protect personnel, this form of mitigation may represent an alternate solution to an interference problem.

15.15 Resonant Shunts: Installation of resonant shunts or filters may provide the only solution to some noise cases such as those resulting from large, noisy rectifier installations. This approach can have some disadvantages which might offset any beneficial effects.

15.151 In addition to the added costs, the design of these filters is quite difficult. This is due to the changing, nonlinear characteristics of the power systems.

15.152 In some cases, installation of a resonant shunt will provide the desired suppression of the harmonic(s) for which designed only to increase the interference from another harmonic.

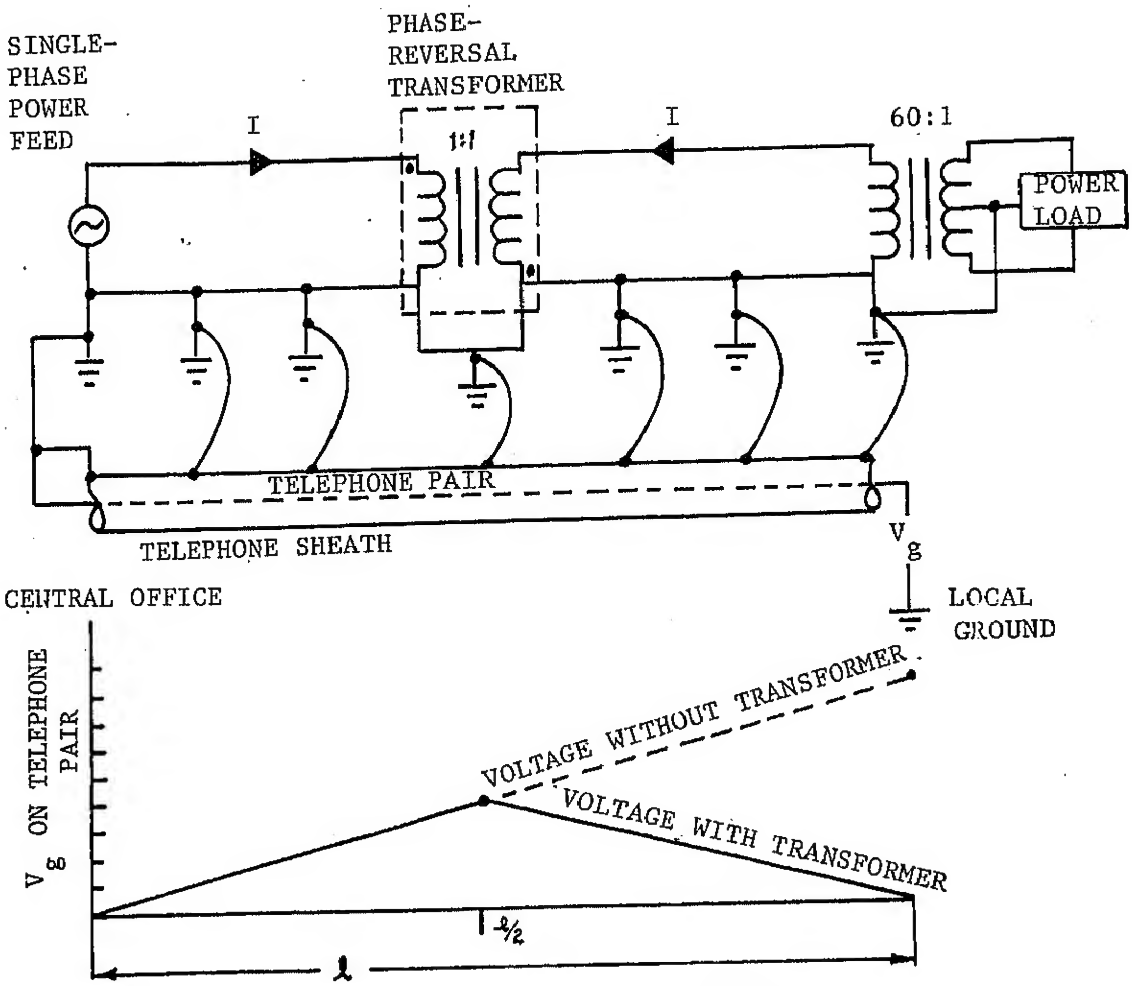
15.16 Booster Transfomers: Amplication of booster transformers is another method which can help reduce interference. This is accomplished by winding the power line and neutral wires into transformer coils as shown in Figure 22. A voltage is thus induced in the return path with a direction and magnitude such that the current is constrained to flow in the neutral conductor rather than the earth. This method is effective only when low impedance grounds are removed from that section of the exposure near the transformer. Installation of a booster transformer also has the undesired effect of another series element in the power line.



Booster Transformer

FIGURE 22

15.17 Phase-Reversal Transformer: Interference may also be effectively reduced through installation of a phase-reversal transformer approximately midway along a power line as illustrated in Figure 23. The induced voltage profile shows the theoretical reductions of maximum induced voltage. Again, there is the probelm of an added series element in the power system and the cost of the installed transformer.



VOLTAGE PROFILE FOR UNIFORM EXPOSURE

Phase-Reversal Transformer

FIGURE 23

15.18 Summary: There are various methods available for reducing the influence of the power system, the susceptibility of the telephone plant or the coupling between them. The most effective means of achieving compatibility between the telephone and the power system is through the inductive coordination process.

15.181 There will be unusual situations where the only practical solution to a noise problem will be the installation of additional elements or devices into either the power plant, the telephone plant, or both, which will reduce or eliminate the interference. All alternatives should be considered with their effects on power and telephone system reliability, performance, and associated economic impact.

15.182 All modifications for purposes of mitigation have undesirable effects on either the power or telephone system in which they are placed. Addition of series elements or devices is equally of concern to both power and telephone engineers.

15.183 The ideal solution must consider operational and maintenance factors as they relate to the economics of each system.

15.19 Carrier Systems: There will occur situations where there is no practical means of mitigation for either the power or telephone companies or, a noise problem has been mitigated but a few circuits in the telephone system still have excessive noise. A trunk or subscriber carrier system should be considered as a solution. Effects of harmonic interference are minimal at carrier frequencies. The voice frequency drop can be maintained in lengths short enough to have low power influence where exposed to parallel power systems. The application of carrier may not be satisfactory if there is excessive 60 Hertz induced longitudinal voltage present. This voltage should first be reduced. (See paragraph 15.07)

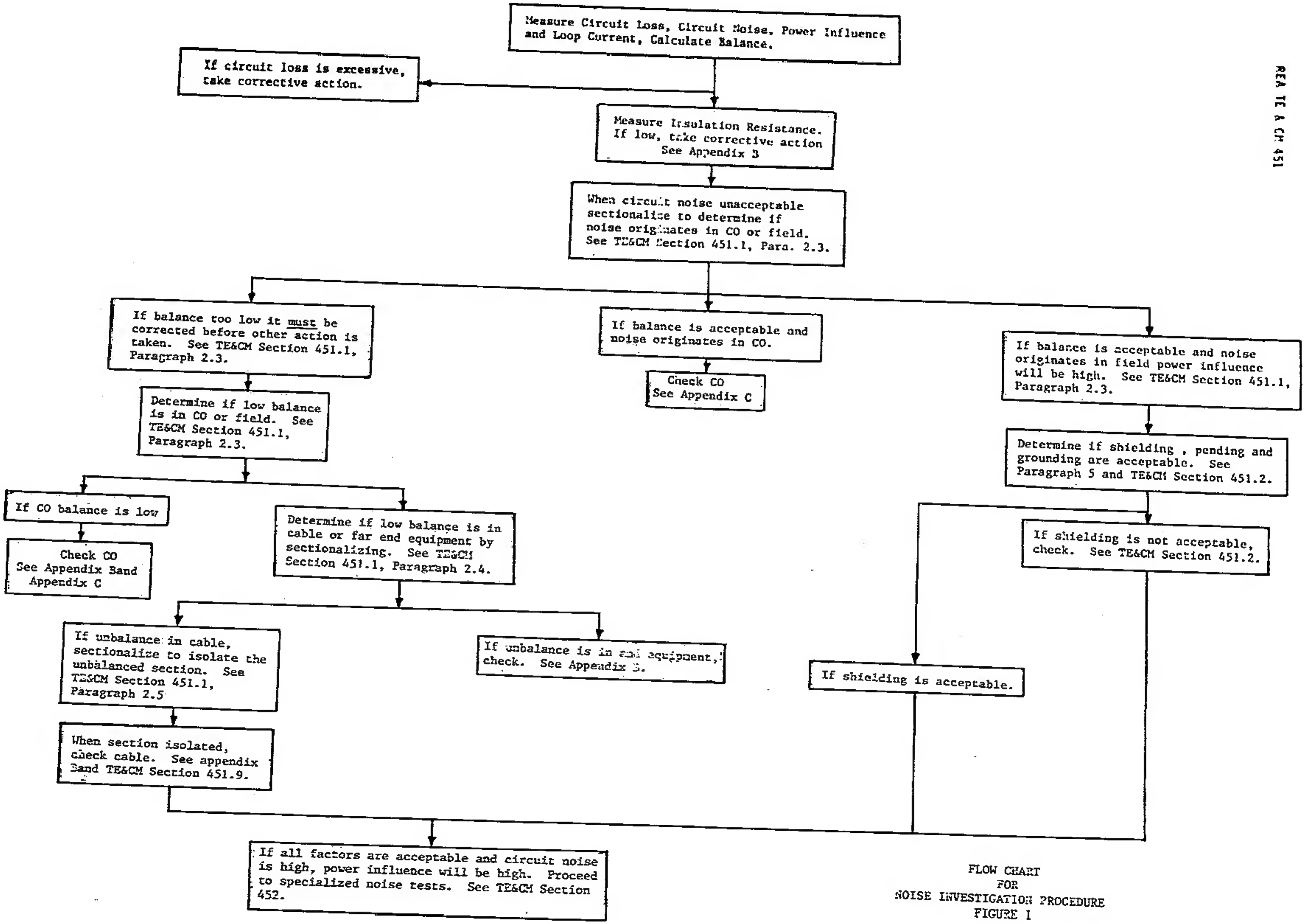
APPENDIX A
FLOW CHART FOR NOISE INVESTIGATION PROCEDURE

1. GENERAL

1.1 Figure 1 presents a flow chart for a noise investigation procedure. It is designed to provide a craftsperson a step-by-step approach to the initial noise investigation. Do not make assumptions and bypass any steps for the one passed might provide the solution.

1.2 Although many problems will be solved there is always a possibility that after completing the initial investigation, it will be necessary to proceed to specialized techniques which are discussed in TE&CM Section 452. Results of all measurements should be recorded so there will be no need for repeating any steps before proceeding with the specialized measurements.

1.3 The initial measurement shown in the first box of the flow chart will usually be completed at the subscriber location by maintenance forces responding to a noise complaint.



FLOW CHART
FOR
NOISE INVESTIGATION PROCEDURE
FIGURE 1

APPENDIX B
CHECK LIST OF
POTENTIAL NOISE FACTORS

1. GENERAL

1.1 The following check lists are provided to assist in locating the major factor(s) contributing to a noise problem. They are grouped into categories that are readily identified during noise isolation procedures.

2. INSULATION RESISTANCE

2.1 Open Wire: When recorded results from insulation resistance tests have indicated leakage to ground exists, the following items should be checked.

2.11 Drainage Units: Inspect for clean carbons. Replace carbons with new ones if necessary. Replace unit with one known to be good. Consideration might be given to replacing carbon arrestors with gas tube arrestors where possible.

SAFETY NOTE: Disconnecting the drainage unit may result in a voltage rise on the line.

2.12 Carrier System Low Pass Filters: Inspect for clean carbons and proceed as in Paragraph 2.11 above.

2.13 Carbon Blocks: Inspect all carbon blocks in the entire line. Clean or replace dirty blocks. Replace any damaged or bad blocks.

2.14 Tree Limbs: Inspect entire length of line. Trim as required.

2.15 Broken Insulators: Inspect. Replace broken ones.

2.16 Crows Nests: Find and remove.

2.17 Spider Webs and/or Insect Nests at Station Protector: Inspect, kill spiders and insects, eliminate eggs, destroy webs and nests.

2.2 Cable Plant: When recorded results from insulation resistance tests have indicated leakage to ground exists, the following items should be checked.

2.21 Drainage Units: Inspect for clean carbons. Replace carbons with new ones, if necessary. Replace unit with one known to be good. Consideration might be given to replacing carbon arrestors with gas tube arrestors. Drainage units are usually not installed on cable plant.

SAFETY NOTE: Disconnecting the drainage unit may result in a voltage rise on the line.

2.22 Carrier System Low Pass Filter: Inspect the clean carbons and proceed as in Paragraph 2.21 above.

2.23 Carbon Blocks: Inspect all carbon blocks in the entire line. Clean or replace dirty blocks. Replace any damaged or bad blocks.

2.24 Spider Webs and/or Insect Nests: Inspect pedestals, station protectors and similar structures. Kill spiders and/or insects and eliminate eggs. Destroy webs and nests.

2.25 Underground Splices: Measure insulation resistance (between the nearest points in ready access or buried plant pedestal housings) to determine insulation level.

2.26 Water in Cable or Moisture: Determine its effect by measuring insulation resistance of pair tip-to-ground and ring-to-ground. Insulation should be high and values should be approximately equal for each conductor to ground.

2.27 Terminal Blocks: Inspect and clean.

2.28 Bridged Tap Isolators: Inspect by removing them to determine if they are a factor. Under some arrangements in the presence of high longitudinal induction these devices can generate harmonics.

3. CENTRAL OFFICE

3.1 When recorded results from noise isolation procedures have indicated that the major factor contributing to the noise problem is in the central office the following items should be checked.

3.11 Heat Coils: Measure the resistance. Resistance should be less than 0.1 ohms. Replace the heat coils with units known to be good.

3.12 Central Office Ground: Measure with ground resistance meter. Value should be less than one ohm.

3.13 Battery Supply Ground: Positive terminal of the main battery should be connected directly to the main central office ground and should be isolated electrically from all other ground points. Check that connecting bolts are tight and connections are clean and corrosion free.

3.14 Coupling in Battery Leads: Common batteries for signaling and talking can conduct voice frequency noise from noisy circuits to circuits. When this is determined to be the case, decentralized filters ›e L configuration can be used. The L filter configuration has component ›s of approximately one millihenry and 7,000 microfarads. This condition rarely be found since specifications require battery filters in central ›es.

Mainframe Coupling: Signaling and battery feed relays sharing the same frame may conduct noise in cable pairs due to insufficient pling in the battery between the battery feed and signaling relays. This sically "crosstalk" noise.

3.16 Electronic Loop Extenders: High induced longitudinal 60 Hertz voltage can saturate these devices and they will generate harmonics in the voice frequency range.

3.17 Additional Information on Central Office Unbalance: Refer to Appendix C for discussion of the sources of unbalance in the central office and associated equipment.

4. STATION EQUIPMENT AND WIRING

4.1 When recorded results from noise isolation procedures have indicated that the major factor contributing to the noise problem is in the station equipment and/or wiring the following items should be checked.

4.11 Carbon Blocks: Inspect. Clean or replace dirty blocks. Replace damaged or defective carbon blocks.

4.12 Station Fuses: Check for corrosion. Clean fuse holder contacts. Replace both fuses with units known to be good.

4.13 Spider Webs and/or Insect Nests: Inspect station protectors. Kill spiders and/or insects and eliminate eggs. Destroy webs and nests.

4.14 Station Wiring: Inspect wiring between station and station protector.

4.15 Ringers: Check that the ringer is a high impedance type. Determine that the ringer has been properly wired such as being connected for bridged ringing when it is being used in a bridged ringing application. Where divided ringing is used, check to see that all ringers on the line are balanced for frequency and location. Improper connection of customer owned equipment may also be a problem.

5. OUTSIDE PLANT

5.1 When recorded results from noise isolation procedures have indicated that the major factor contributing to the noise problem is in a specific part of the outside plant, the following plant items should be checked.

5.2 Open Wire:

5.21 DC Loop Resistance Unbalance: This should not be a factor, except where the open wire portion of the loop is very long. A T&R reversal will prove conclusively if the resistance unbalance is a contributing factor. Refer to Paragraph 15.04 of TE&CM Section 451 for a discussion of resistance unbalance.

5.22 Splices and Splice Sleeves: Inspect all splices. Replace all splices or splice sleeves known or suspected to be defective.

5.23 Open Wire Taps: Continue isolation procedures to isolate the location of the problem.

5.24 Bridged Tap Isolators: These devices are not designed for use on open wire. Search for and remove any that are found.

5.25 Line Sag: Check for equal line sag. Correct where necessary.

5.26 Transposition Errors: Check actual line against applicable transposition scheme. Correct any irregularities found.

5.3 Cable:

5.31 DC Loop Resistance Unbalance: Measure resistance unbalance with a wheatstone bridge as shown in Figure 7 of TE&CM Section 451.3. Refer to Paragraph 15.09 of TE&CM Section 451 for a discussion of the effects of resistance unbalance.

5.32 Splice Connectors: Inspect all splices. Replace all splices found or suspected to be defective.

5.33 Capacitance Unblance: Measure the capacitance unbalance of the pair by using the procedure shown in Figure 4 of TE&CM Section 451.3. It is suggested that the test length be limited to 4.5 to 6.0 kilofeet (loading section length). The magnitude of capacitance should meet limiting values in applicable cable specifications.

NOTE: See TE&CM Section 451 for a discussion of determining capacitance unbalance from longitudinal balance measurements. This technique utilizes test equipment less expensive and complex than that required for direct measurement of capacitance unbalance.

APPENDIX C
CENTRAL OFFICE EQUIPMENT

1. The following discussion shows where unbalances can occur in central office and associated equipment installed on the office side of the MDF.

1.1 Figure 1a shows a connector or transmission bridge in the talking condition. An unbalance can occur in the battery feed relay(s) and or in the capacitors.

1.11 Modern battery feed relays are usually well balanced. Occasionally some older equipment will be found where relay unbalance exists. These should be replaced with better balanced relays.

1.12 Some of the modern electronic offices utilize repeating coil coupling between the switching equipment and the cable pair. These should also be relatively well balanced.

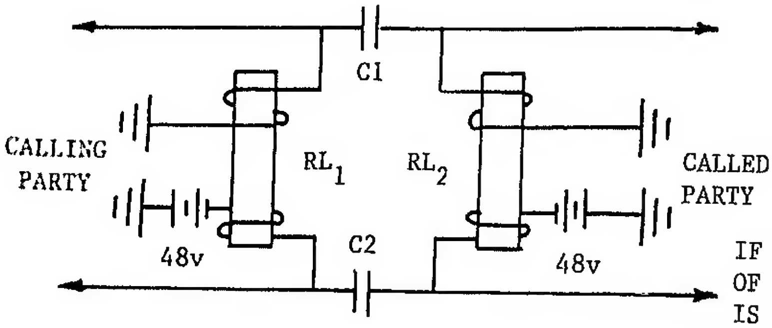
1.2 Bridge type long line adapter equipment (Figure 1b & c) may occasionally be found to have insufficient balance. A repeating coil type long line adapter unit will provide better balance.

1.3 Relays providing talking battery during revertive call connections may occasionally be found unbalanced. This is because a different relay (signaling type) other than a battery feed, which is usually well balanced, may be providing the talking battery.

1.4 Relay saturation resulting in noise may sometimes be encountered. This occurs when very high fundamental frequency induction in the longitudinal circuit has a path to ground through the line relay in the idle condition (or the battery feed relay in the talking condition) and the relay core. The relay windings become non-linear and create harmonics of the fundmental 60 Hertz frequency which are heard on the line as noise. A drainage unit (See Paragraph 15.09) installed at a suitable location will often (not always) correct for this, not because the unit is a noise filter, but because it reduces the 60 Hertz current in the CO equipment and thus prevents saturation. Another method for controlling the 60 Hertz current is the installation of a longitudinal choke at the CO. This is discussed in Paragraph 15.06.

1.5 Repeating coils used for trunk circuits are normally well balanced if <u>correctly</u> wired in. No known noise problems have been attributed to repeating coils.

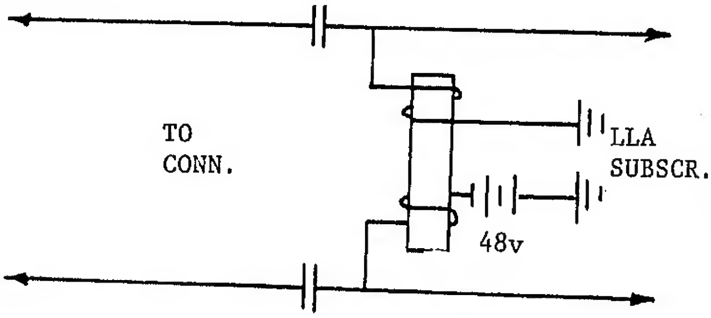
1.51 DX signaling, a dc signaling system for use on trunks has very good balance if properly wired. Check to determine that the 250 ohm balancing resistor and the transmission capacitors <u>are</u> in place. A basic diagram for the unit properly wired is shown in Figure 2. DX signaling is not normally susceptible to relay chatter, although some cases have been reported in the presence of high longitudinal induction.



IF TRANSMISSION CAPACITOR C1 IS NOT WELL MATCHED WITH TRANSMISSION CAPACITOR C2 NOISE CAN RESULT

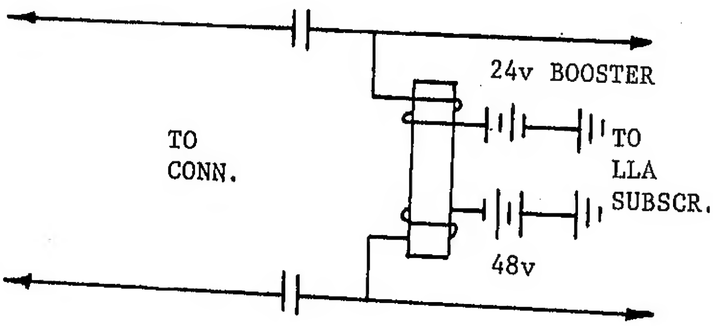
IF THE IMPEDANCE OF THE WINDINGS OF EACH TALKING RELAY RL_1 AND RL_2 IS NOT WELL BALANCED WITH RESPECT TO GROUND NOISE CAN RESULT

A. TYPICAL TRANSMISSION BRIDGE IN C.O. CONNECTOR CIRCUIT



IF THE IMPEDANCE OF THE TALKING BATTERY RELAY WINDINGS IS NOT WELL BALANCED WITH RESPECT TO GROUND NOISE CAN RESULT

B. TYPICAL TRANSMISSION BRIDGE FOR LONG LINE ADAPTER (HALF-BRIDGE)



1. SAME COMMENT AS (B) ABOVE FOR RELAY WINDINGS

2. IF 24v BOOSTER IS NOT WELL FILTERED NOISE CAN RESULT

C. TYPICAL LLA WITH 72 VOLTS (48v C.O. + 24v BOOSTER)

FIGURE 1 TYPICAL TRANSMISSION BRIDGE CIRCUITS FOR LOOP CALLS

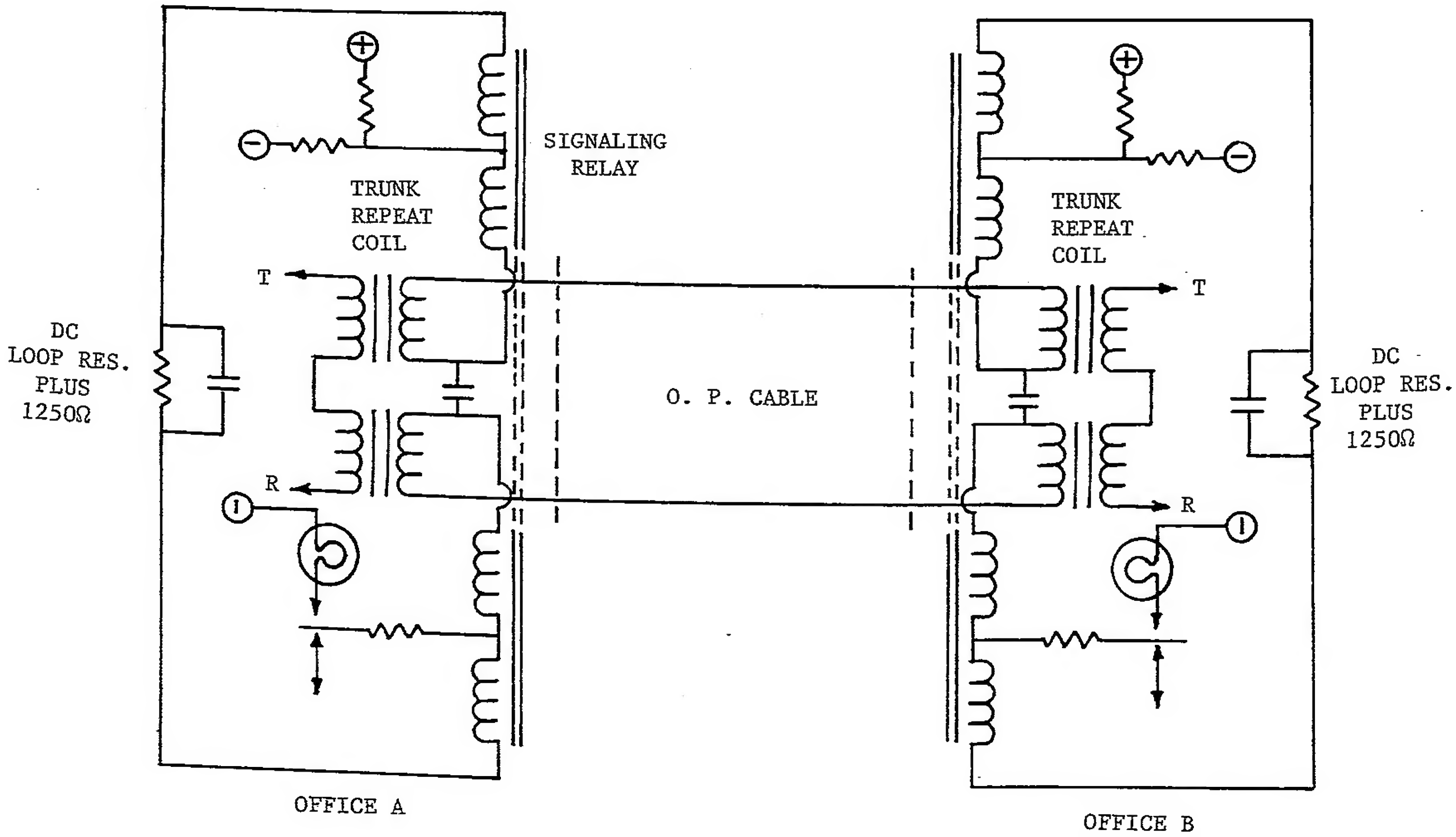
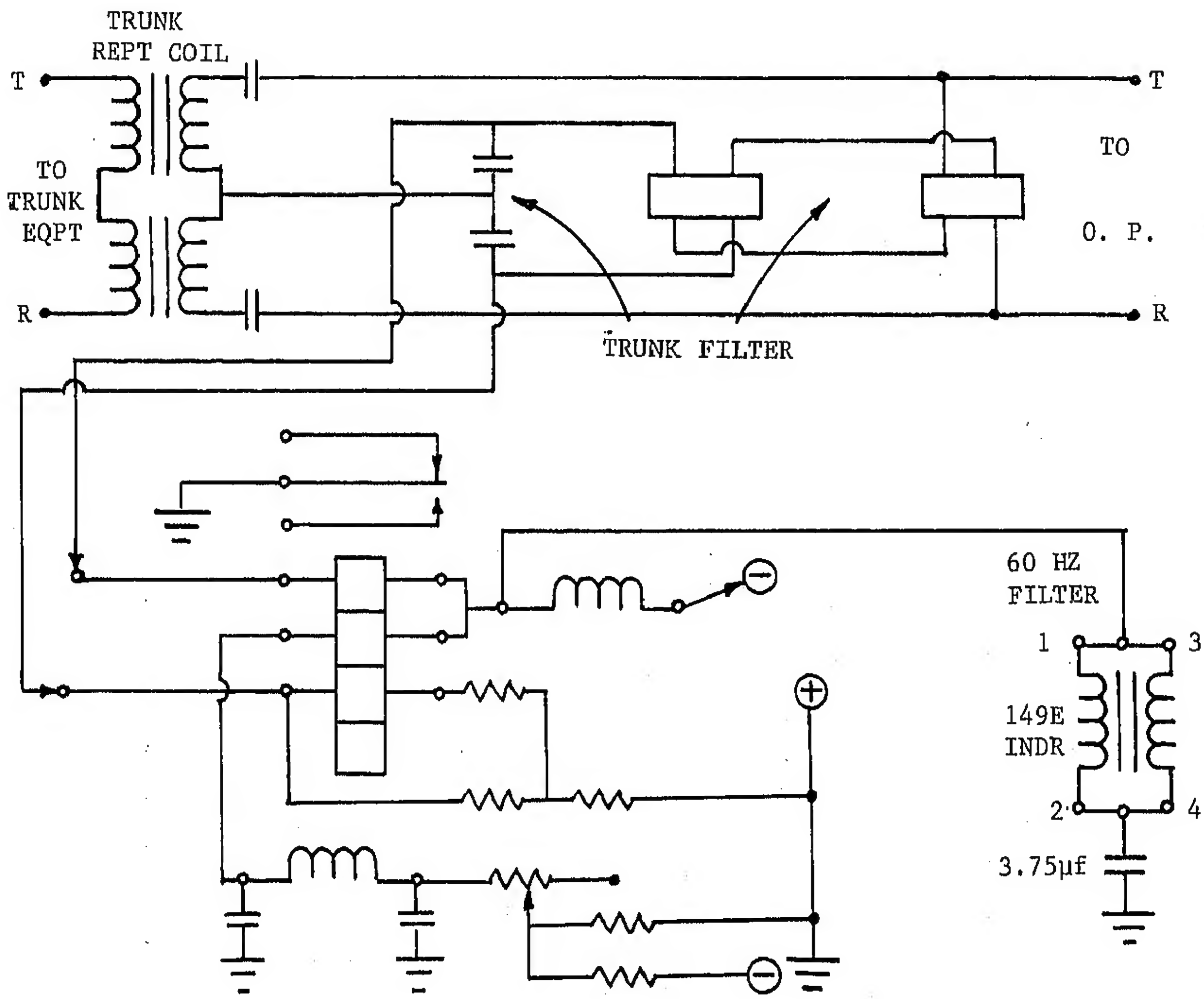


FIGURE 2 DX SIGNALING. PARTIAL SCHEMATIC IN TALKING CONDITION

1.52 Older type CX signaling is shown in Figure 3 in its basic form. This signaling system provides good balance at higher 60 hertz harmonic frequencies, if thump coils are correctly wired-in, but is inherently unbalanced at the low frequencies, particularly 180 hertz and lower. In the past, much of the application for CX signaling was for phantom circuits. CX is no longer the recommended system and its use should be avoided.

1.521 Where CX signaling is used, check for a ground on the line side of the repeating coil. If ground is present, remove. Do this at both ends of the trunk. The ground is not required for either signaling or transmission reasons with non-phantomed circuits. Removing this ground eliminates the noise path which will reduce noise due to outside plant resistance unbalance.



RE 3 CX SIGNALING BASIC CONFIGURATION. ONE END ONLY

1.522 Existing CX equipment can display relay chatter in the idle trunk condition in the presence of few volts to ground of 60 Hertz in- duction at the signaling equipment terminals. The use of 60 Hertz filters such as shown in Figure 3 will correct relay chatter of buzzing in the idle condition of the voltage to ground is less than 40 volts. Filters are required at both ends.

1.53 SX signaling equipment inherently gives good balance. Check to determine that it is wired correctly. It is also subject to relay chatter in the idle condition the same as CX equipment. SX will probably operate with no buzz or relay chatter by treating the signaling ends with the 60 Hertz filters discussed in Paragraph 1.522 above and shown in Figures 4A & 4B. Filters are required at both ends.

1.54 Loop dial signaling equipment may still be found which is un- balanced. Unbalanced relays facing the cable side should be replaced with balanced relay units. On some modern loop dial units occasionally a 1,500 ohm resistor may be found connected from one side of the line to ground, for signaling reasons only, causing noise. This unbalance can be corrected by replacing the resistor with a decade box. Otherwise, loop dial signaling results in a very acceptable noise level, again, if properly wired.

1.55 E-6 type voice frequency repeater equipment works extremely well with DX, SX CX, and Loop Dial signaling systems. An E-6 type repeater can produce noise through saturation. Should the signaling equipment be unbalanced (by reason of incorrect wiring, natural unbalance, etc.) a portion of the noise-to-ground low frequency voltage is across the tip and ring sides or metallic path across the repeater input terminals. This induction saturates the repeater which creates its own harmonics like the line relay (See Paragraph 1.4 above). Presence of such a condition may be easily checked by observing on a noise measuring set whether the magnitude of circuit noise is reduced by the amount of repeater gain (or approximately so) when the repeater is temporarily removed from the circuit. If the reduction is much greater than the repeater gain, repeater saturation is indicated. When the unbalance is removed, this problem is entirely eliminated. Saturation may also occur with certain types of toll ticketing equipment.

1.56 Solid state loop extender and trunk equipment have been developed and are being used in many offices. All these devices are usually well balanced but noise problems can occur due to saturation in the pre- sence of high induced longitudinal voltage. REA attempts to minimize the incidence of this type problem through a simulated longitudinal induction test in the specifications for these devices.

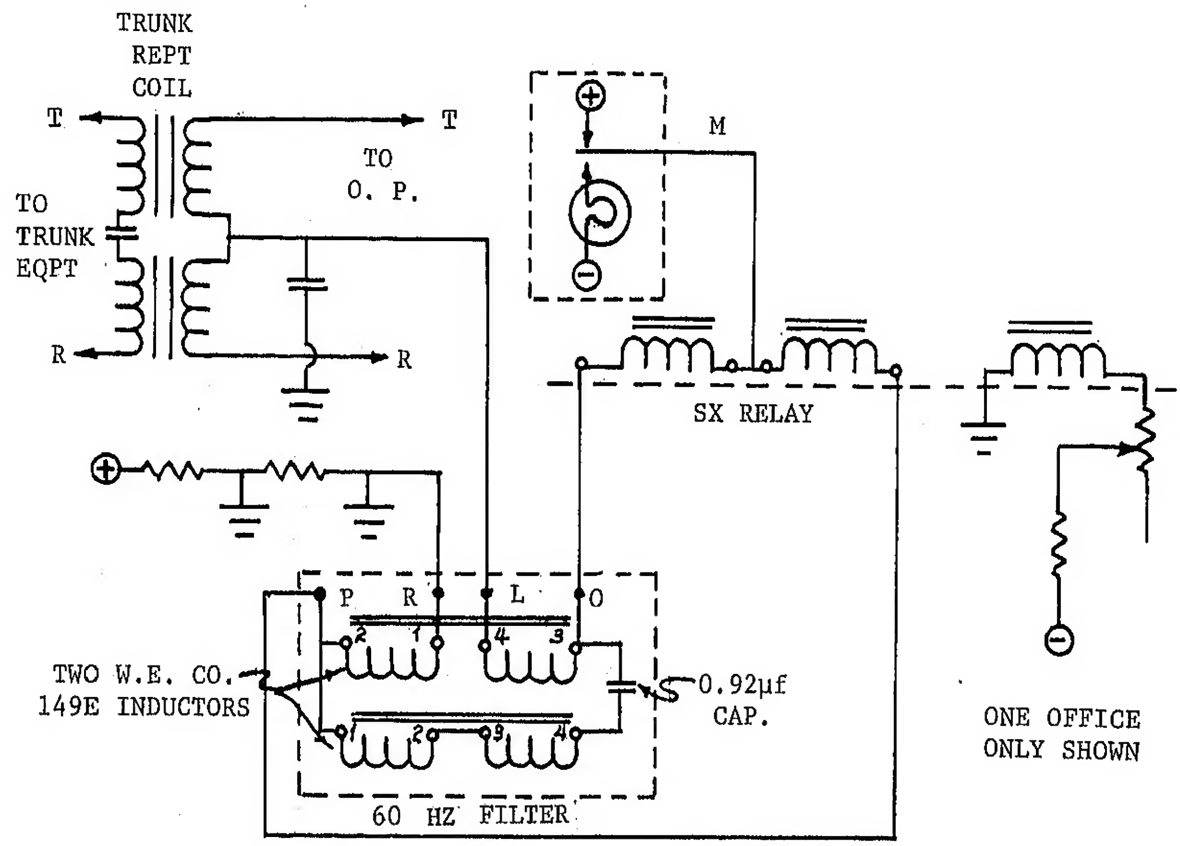


FIGURE 4A SX SIGNALING WITH 60 HZ FILTER FOR ELIMINATING RELAY CHATTER

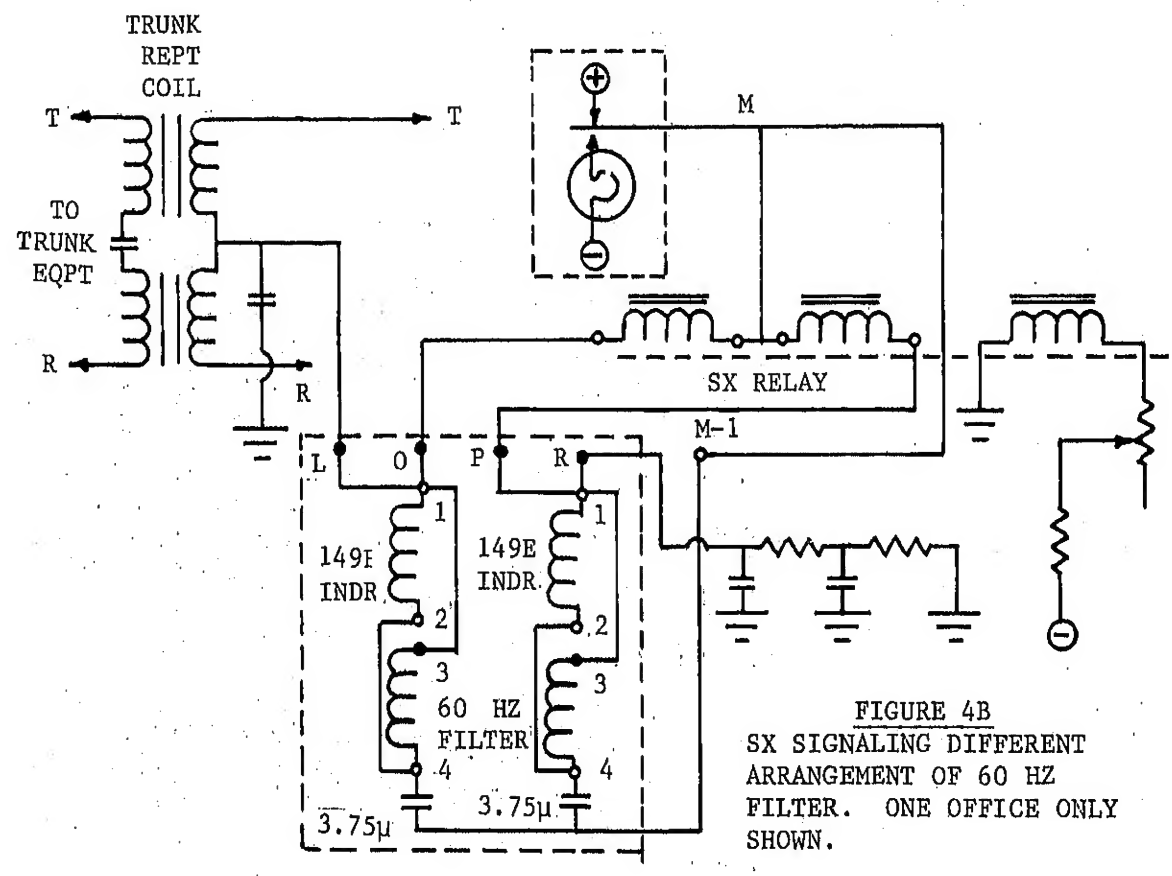


FIGURE 4B
SX SIGNALING DIFFERENT ARRANGEMENT OF 60 HZ FILTER. ONE OFFICE ONLY SHOWN.

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